

ASTRON

Netherlands Institute for Radio Astronomy

Science with LOFAR

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LOFAR Project Scientist
(ASTRON / UvA)

Journées Radio SKA-LOFAR
February 12, 2014

ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)



LOFAR

Science with LOFAR

Current Array Status and Upgrades
Progress with the MSSS Survey
Highlights of Recent Science Results

Journées Radio SKA-LOFAR
February 12, 2014



International LOFAR Telescope

*Europe-wide radio interferometry array @ 10-270 MHz
Resolution: 2 arcmin - 0.3 arcsec*



Onsala

*2010-2012: Commissioning phase
Dec. 2012: Cycle 0 observing cycle
Sep. 2013: Correlator upgrade
Dec. 2013: Start Cycle 1 cycle
Jan. 2014: Cycle 2 call released*



Chilbolton

- 44 operational stations completed
- 38 NL stations, 8 international stations
- 4 new stations funded in:
Germany (1), Poland (3),
- Proposed stations: Ireland (1),
Italy (1), Finland (1), NL (2+)

Hamburg
to come ...

Potsdam

Poland funded

Jülich

Effelsberg

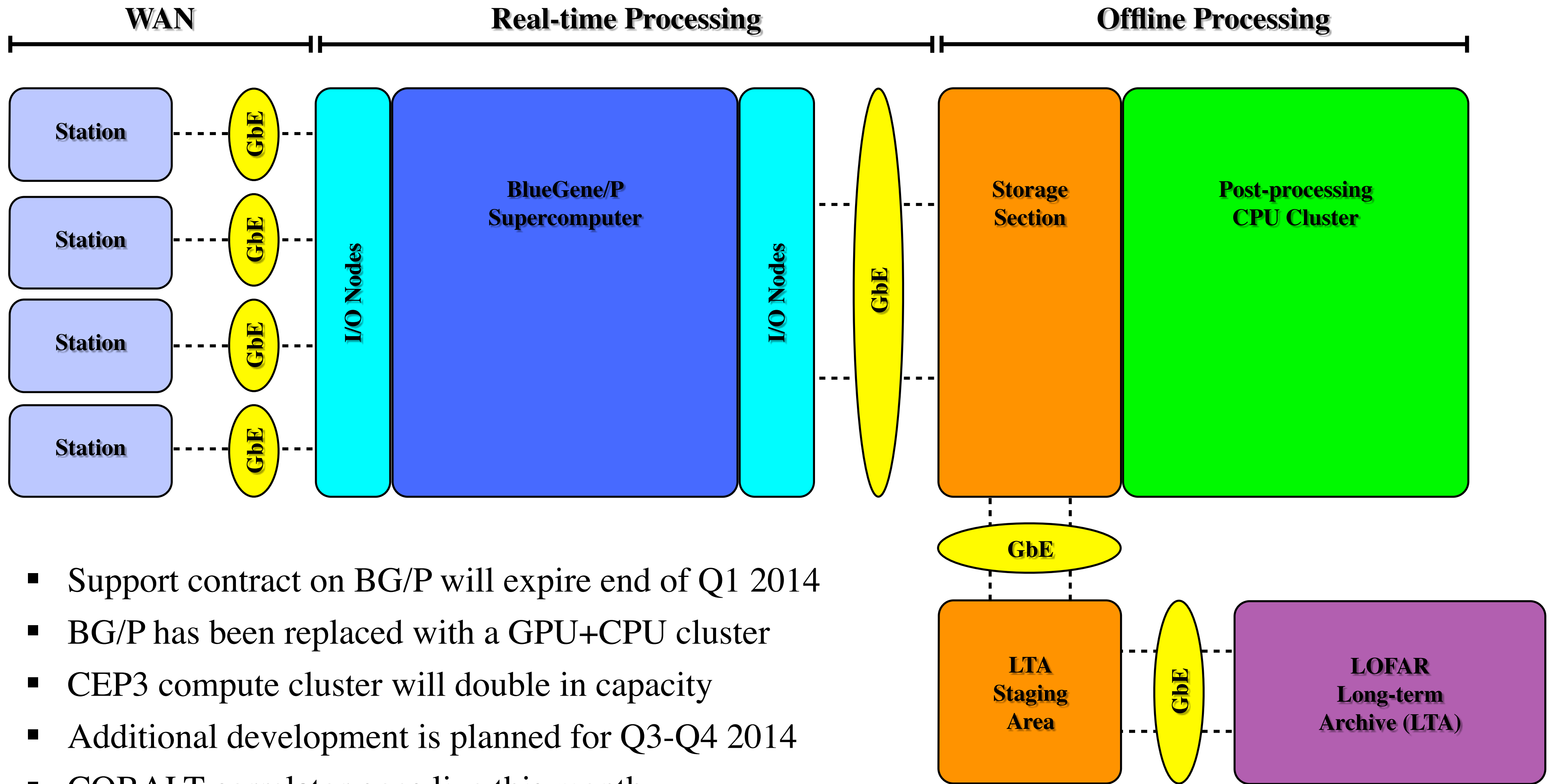
Tautenburg



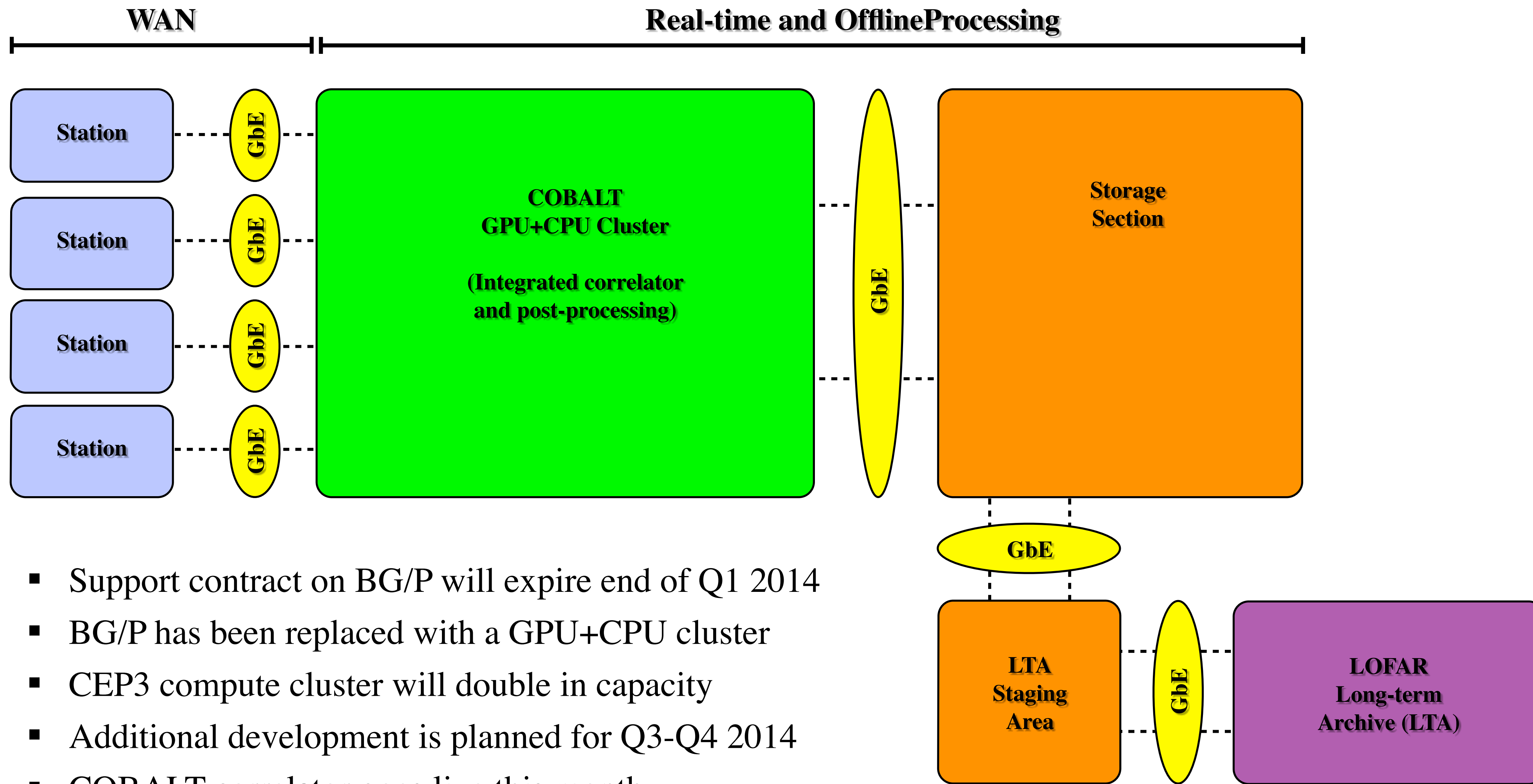
Unterweilenbach



Nançay



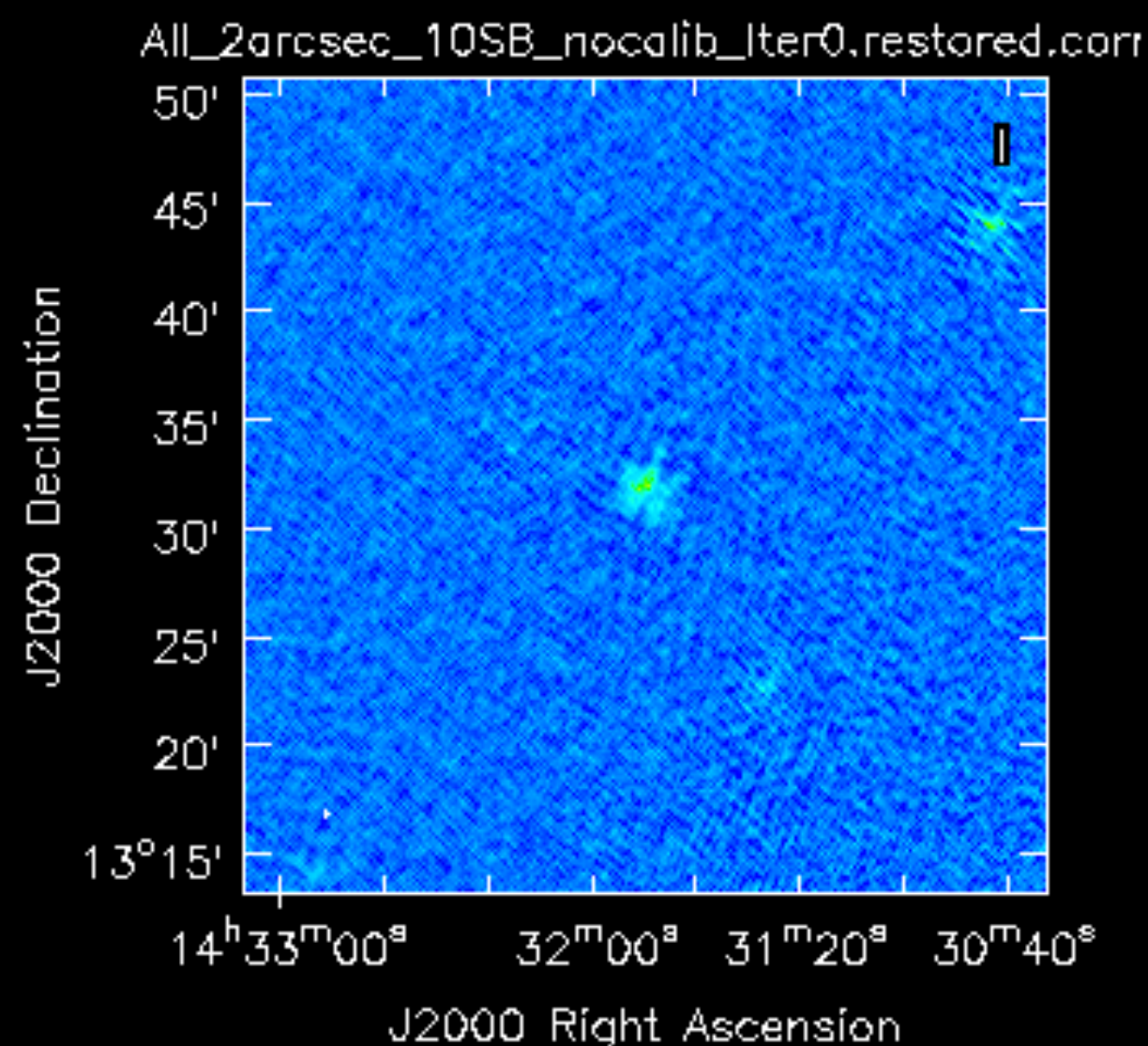
- Support contract on BG/P will expire end of Q1 2014
- BG/P has been replaced with a GPU+CPU cluster
- CEP3 compute cluster will double in capacity
- Additional development is planned for Q3-Q4 2014
- COBALT correlator goes live this month



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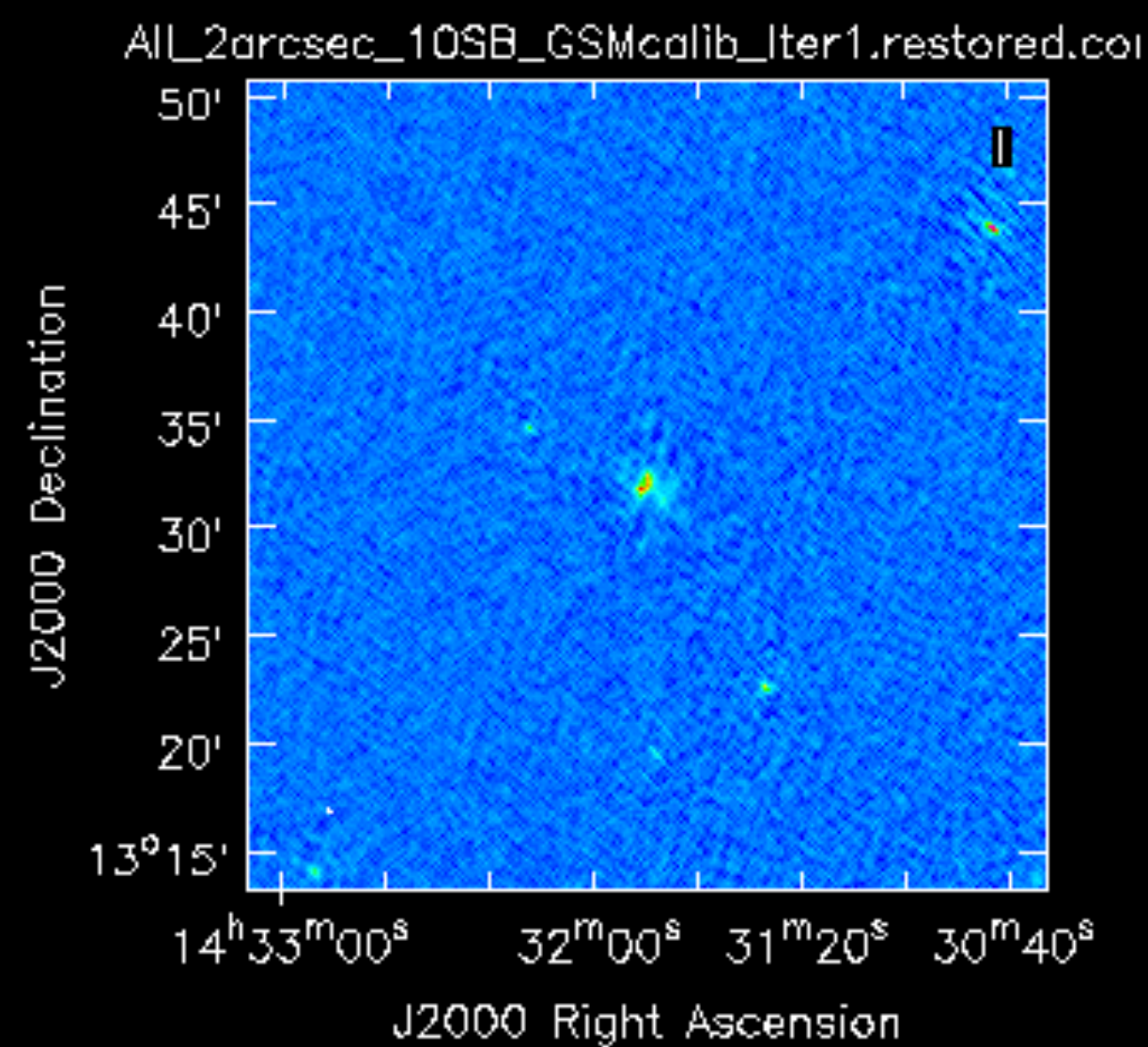
- **Dedicated Imaging and Calibration Tiger Team (Group Leader: G. Heald)**
- **Goal is to reach thermal noise limited imaging with the automated pipeline**
- **Many topics (self-cal, DD effects, performance, smart-demixing, etc.)**

No phase calibration



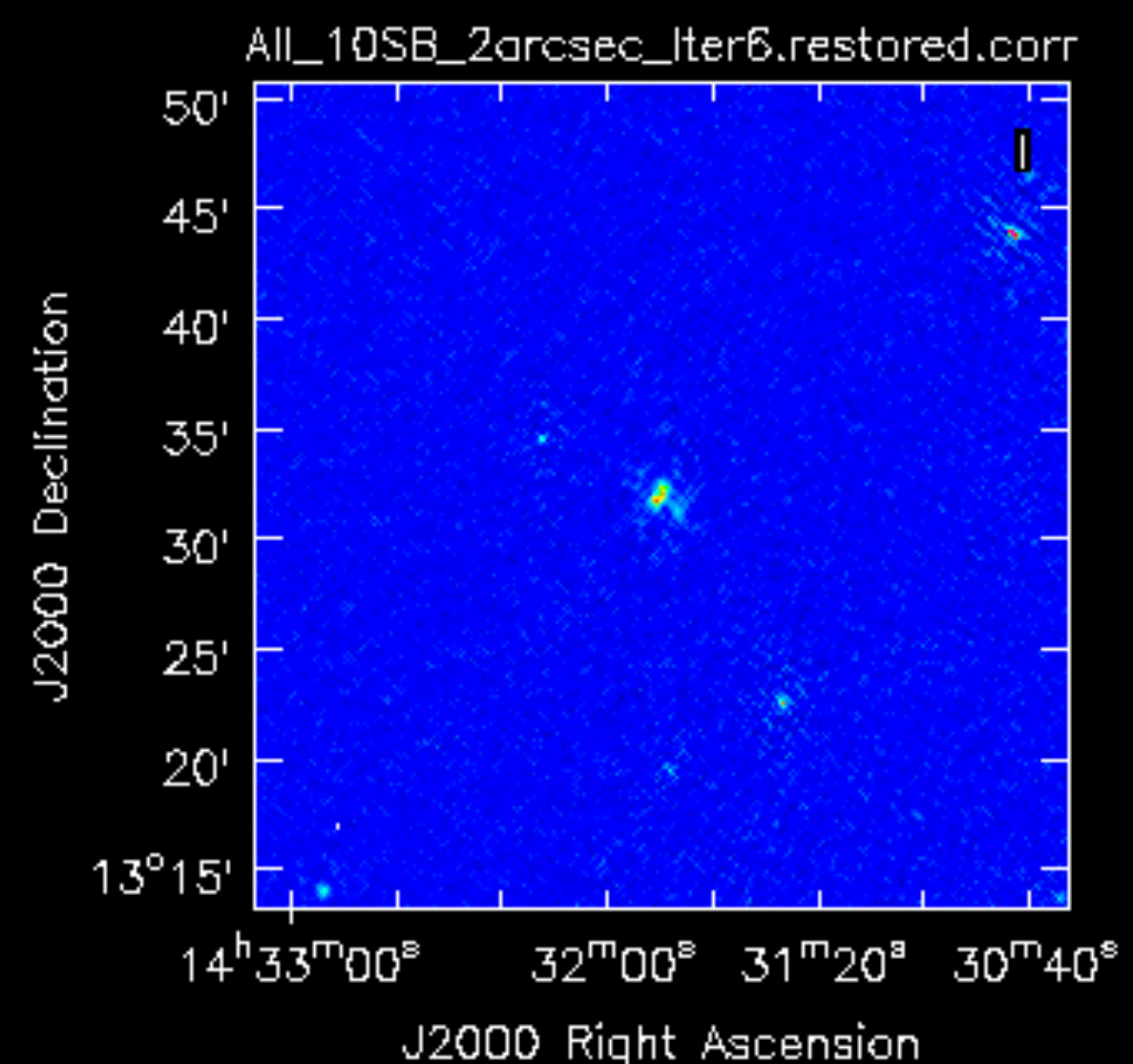
50 mJy

GSM calibration



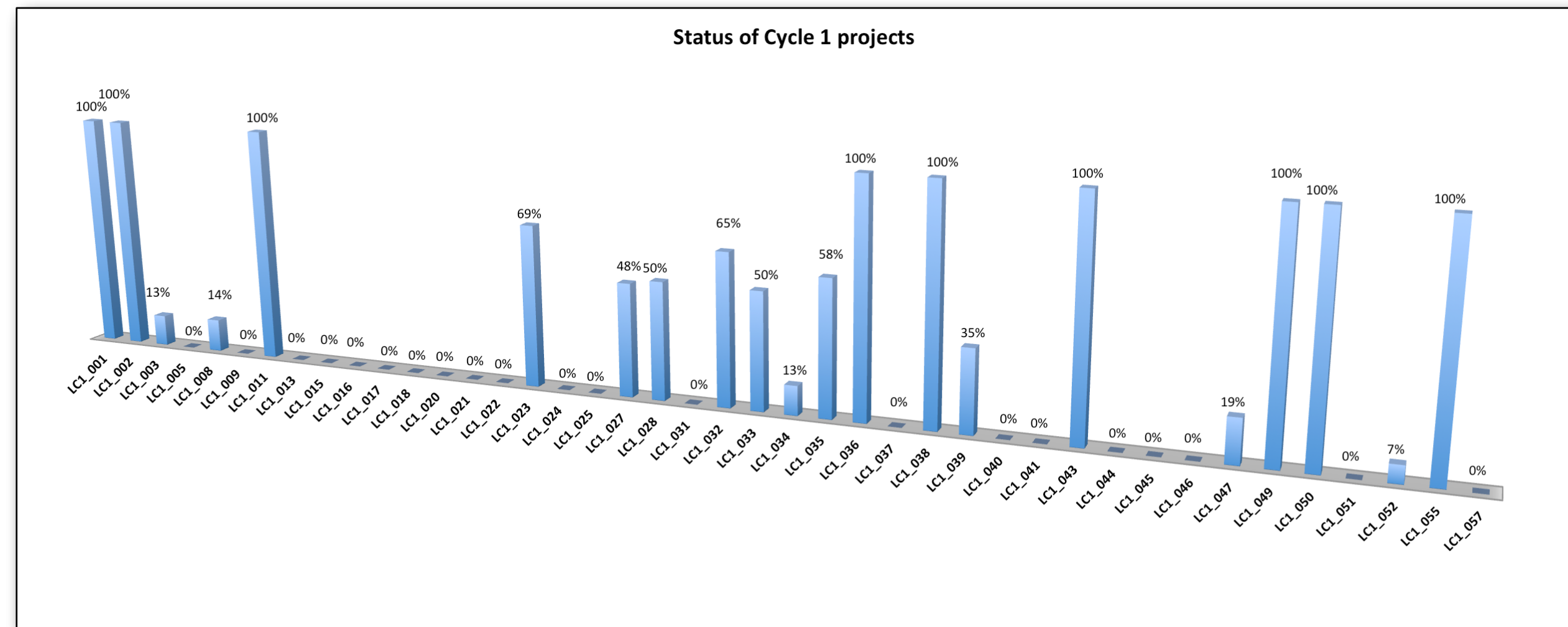
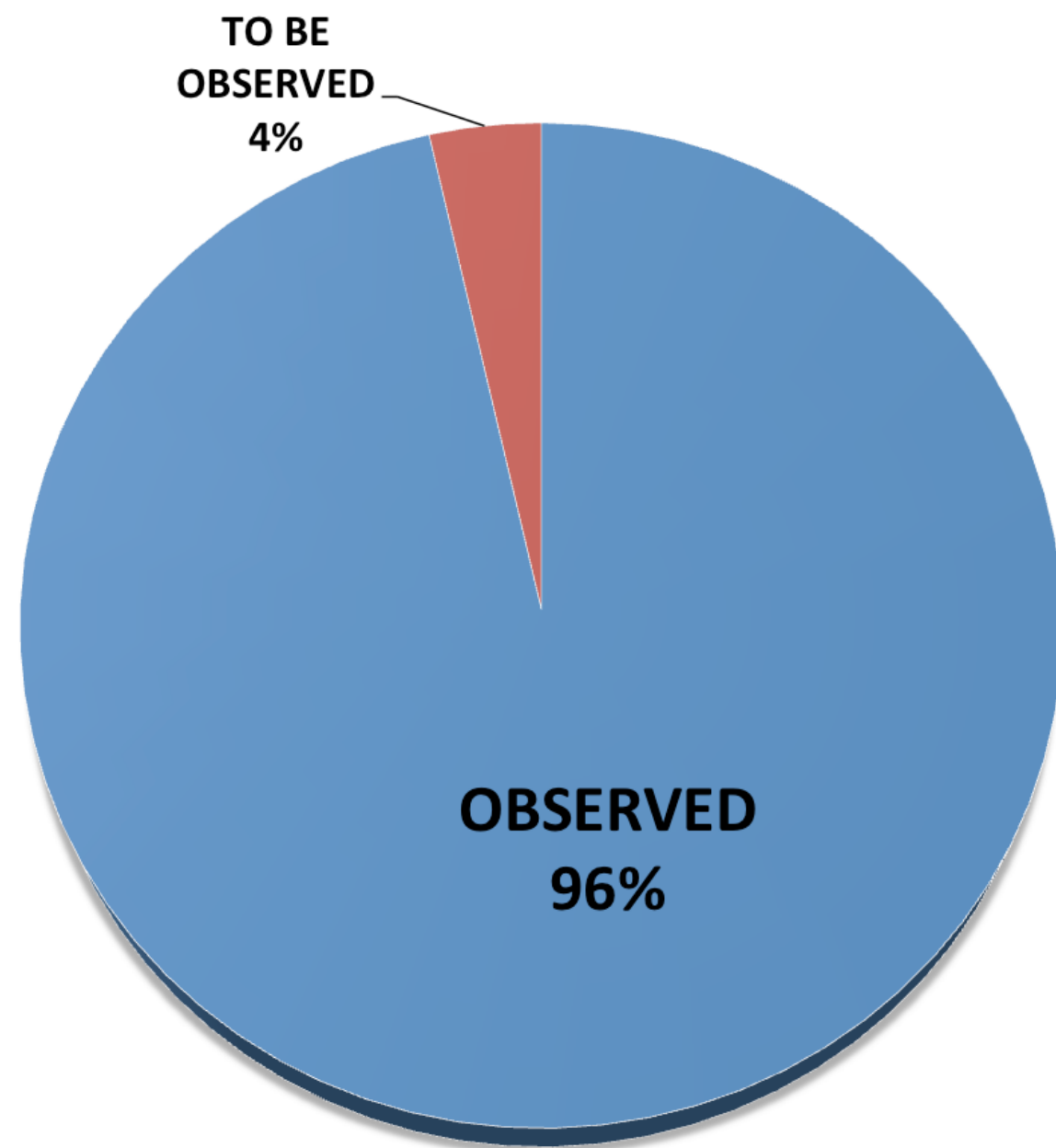
10 mJy

Self-calibration

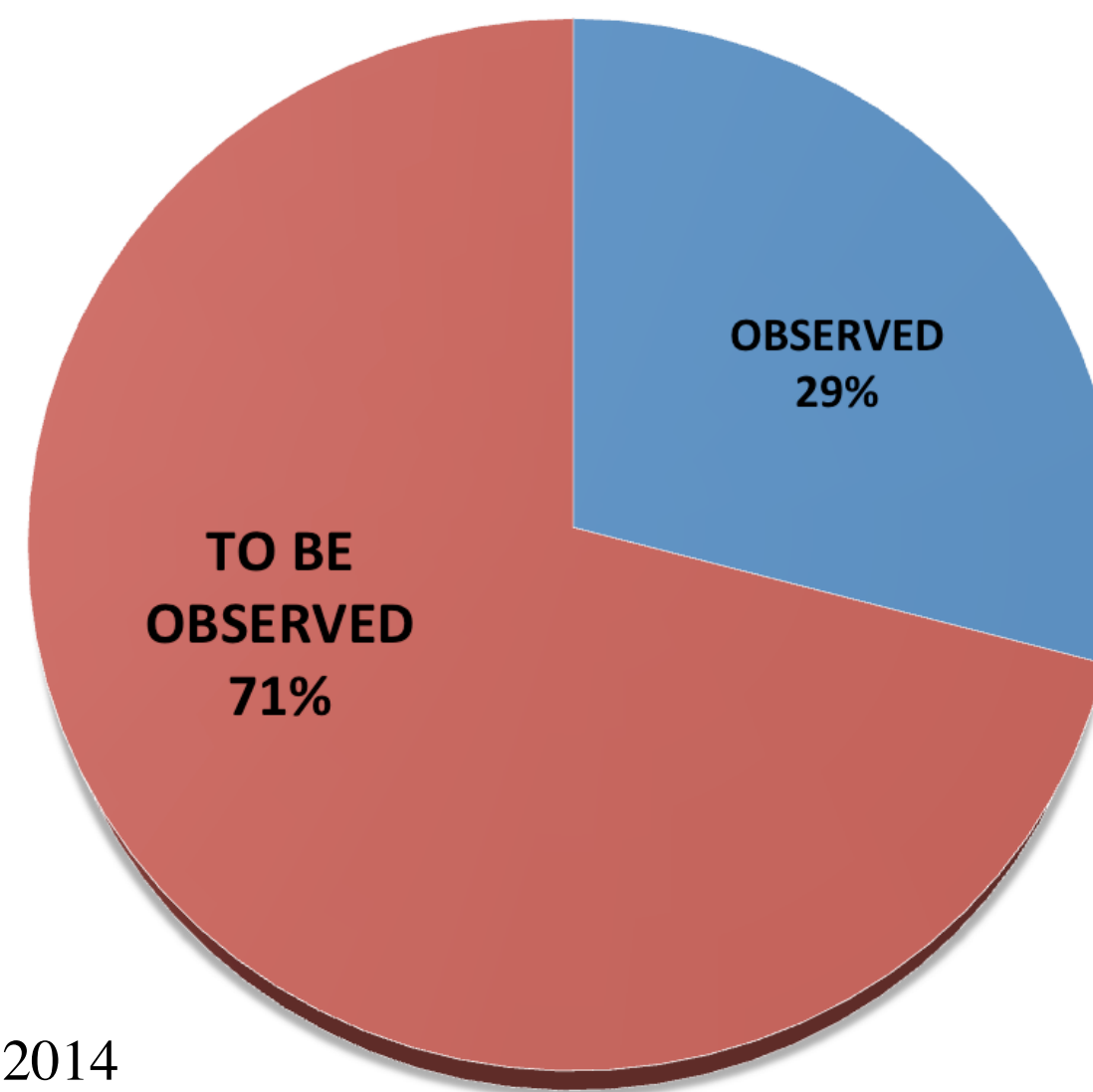


2 mJy

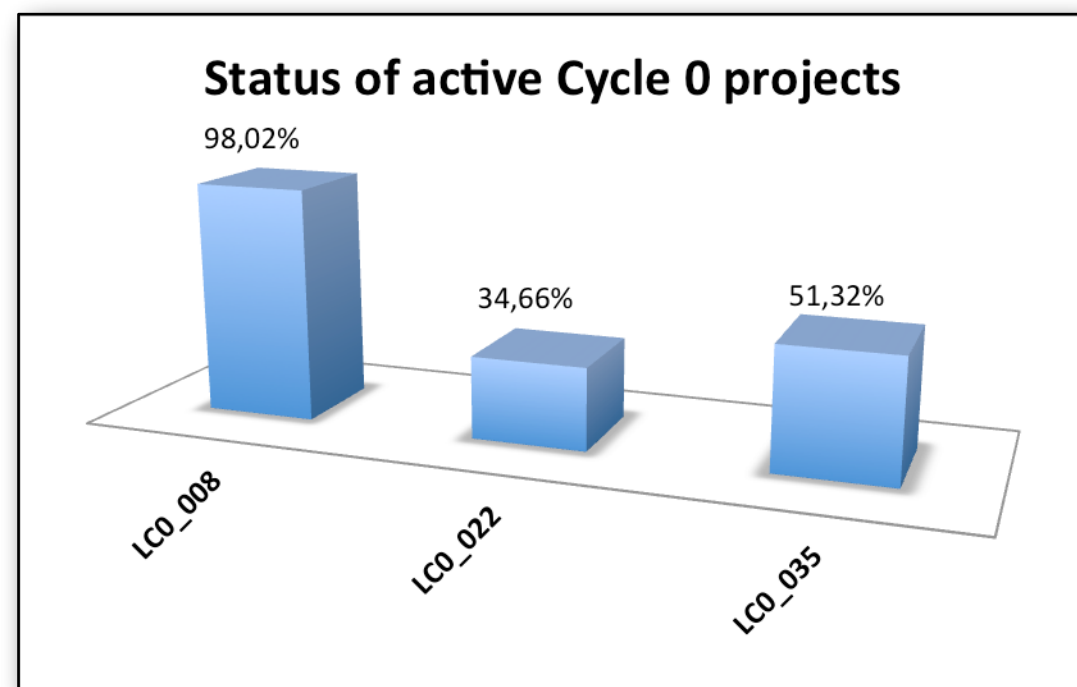
Status of Cycle 0



Status of Cycle 1



- Cycle 0 now mostly complete
- Finishes in Cycle 1 at lower priority
- Cycle 1 began in December 2013
- Cycle 2 call issued January 2014
- Proposals due March 7, 2014
- Cycle 2 observing begins May 2014



(courtesy R. Pizzo and Science Support)

Project Leader: George Heald

MSSS-LBA



Frequency: 30-75 MHz (8 x 2 MHz bands)

Resolution: ≤ 100 arcsec

Sensitivity: ≤ 15 mJy/beam

Area: 20,000 square degrees

Number of Fields: 660

MSSS-HBA



Frequency: 115-180 MHz (8 x 2 MHz bands)

Resolution: ≤ 120 arcsec

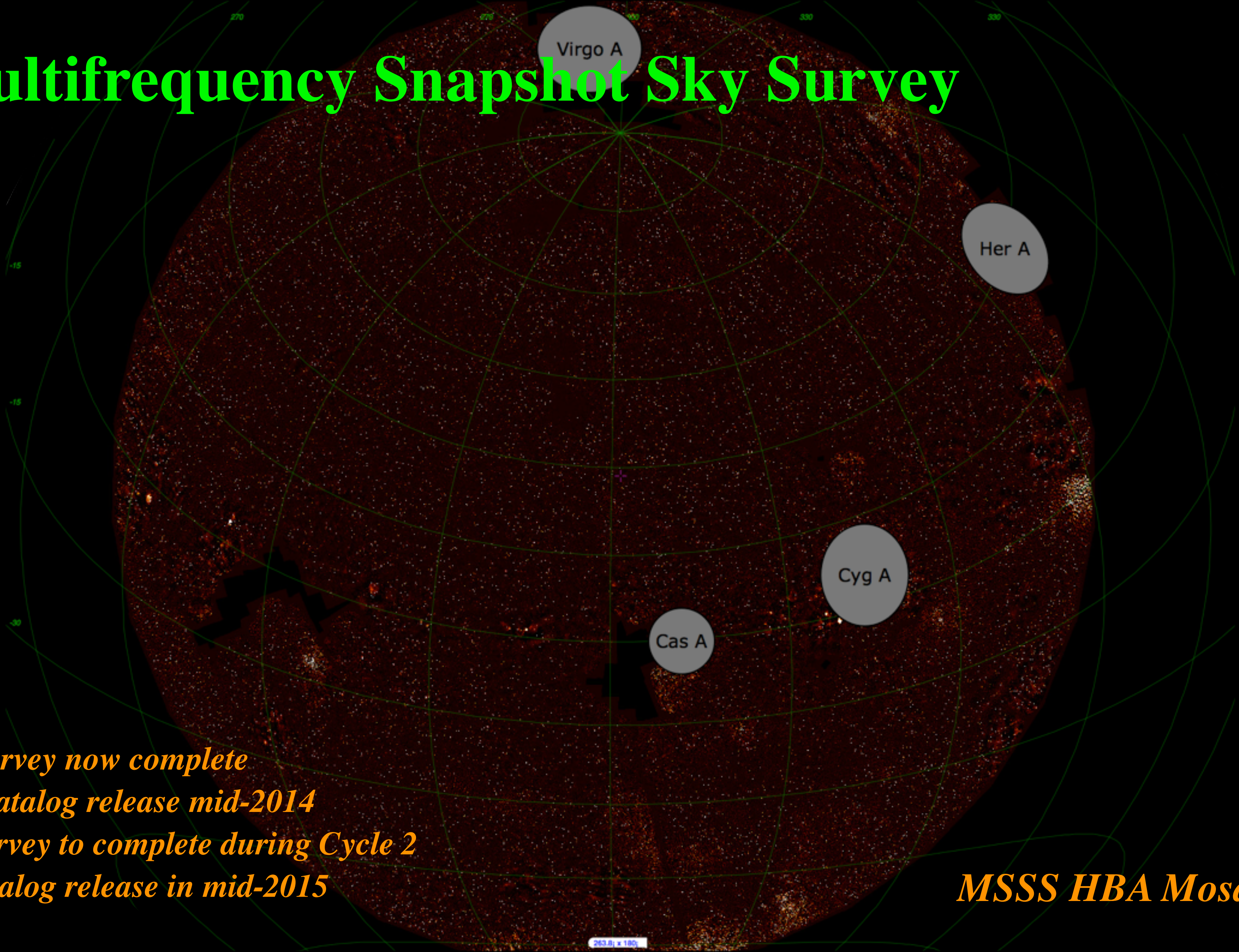
Sensitivity: ≤ 5 mJy/beam

Area: 20,000 square degrees

Number of Fields: 3616

Goals: Obtain broadband sky model, test LOFAR operations

Multifrequency Snapshot Sky Survey



HBA Survey now complete

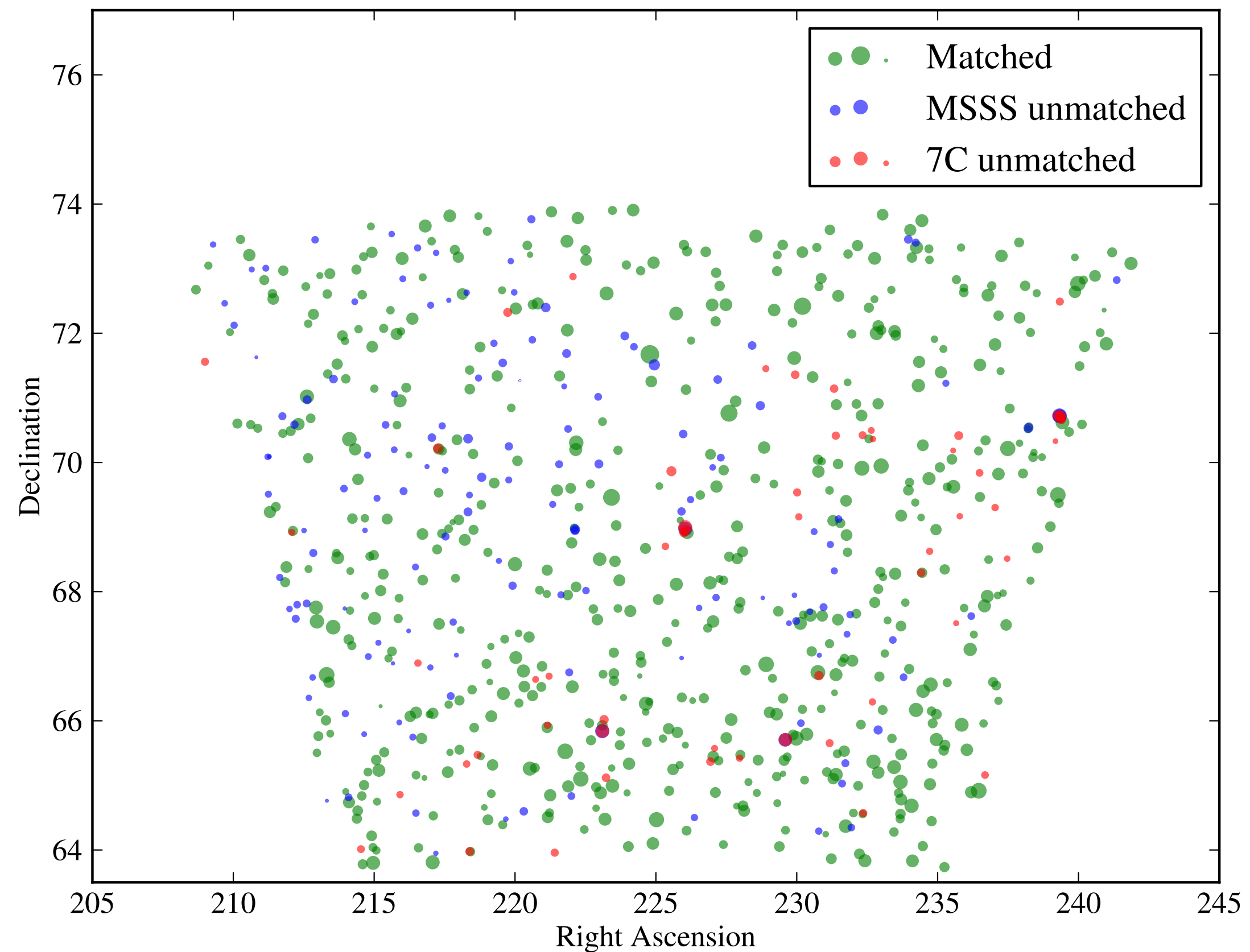
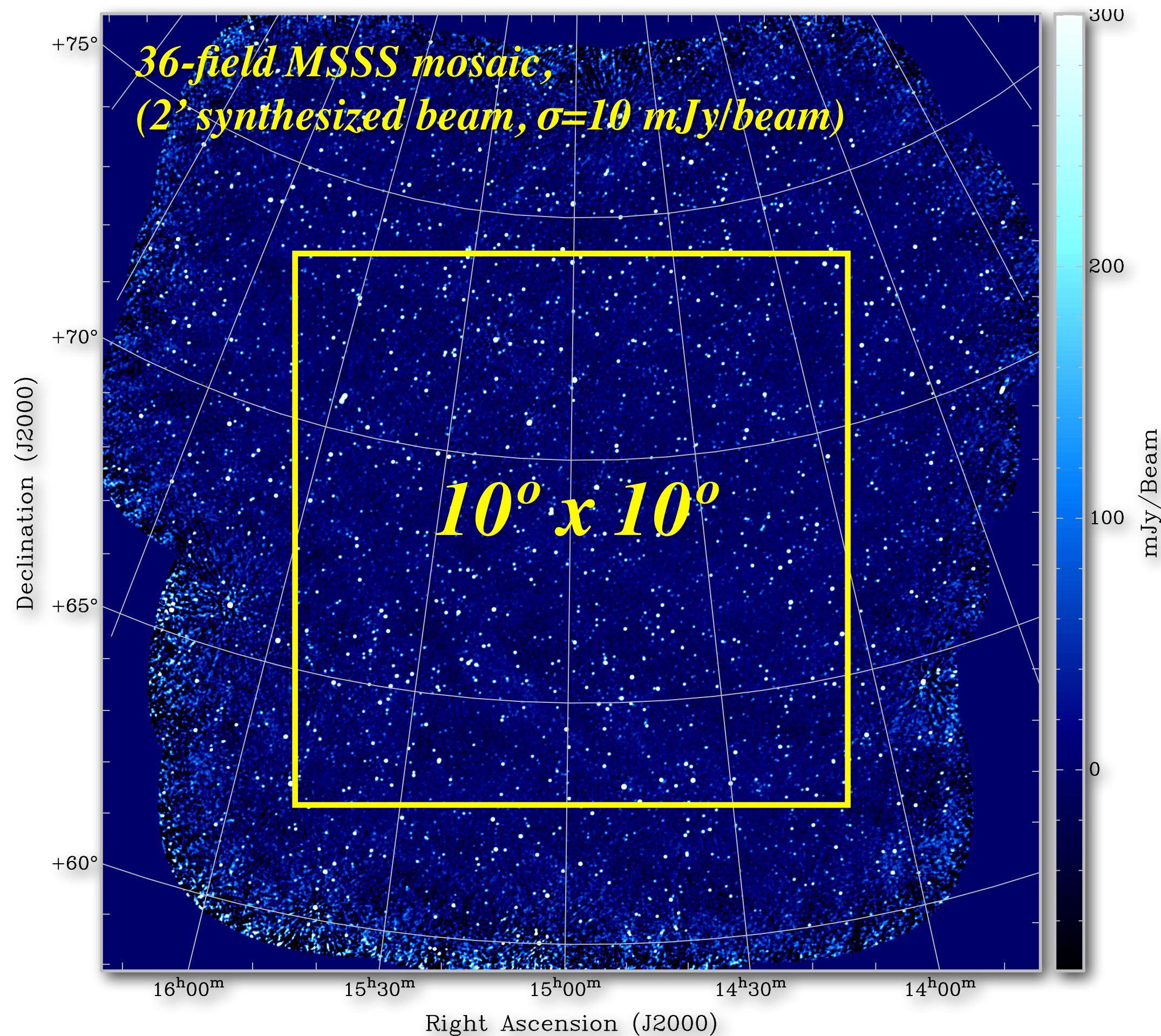
Initial catalog release mid-2014

LBA Survey to complete during Cycle 2

LBA catalog release in mid-2015

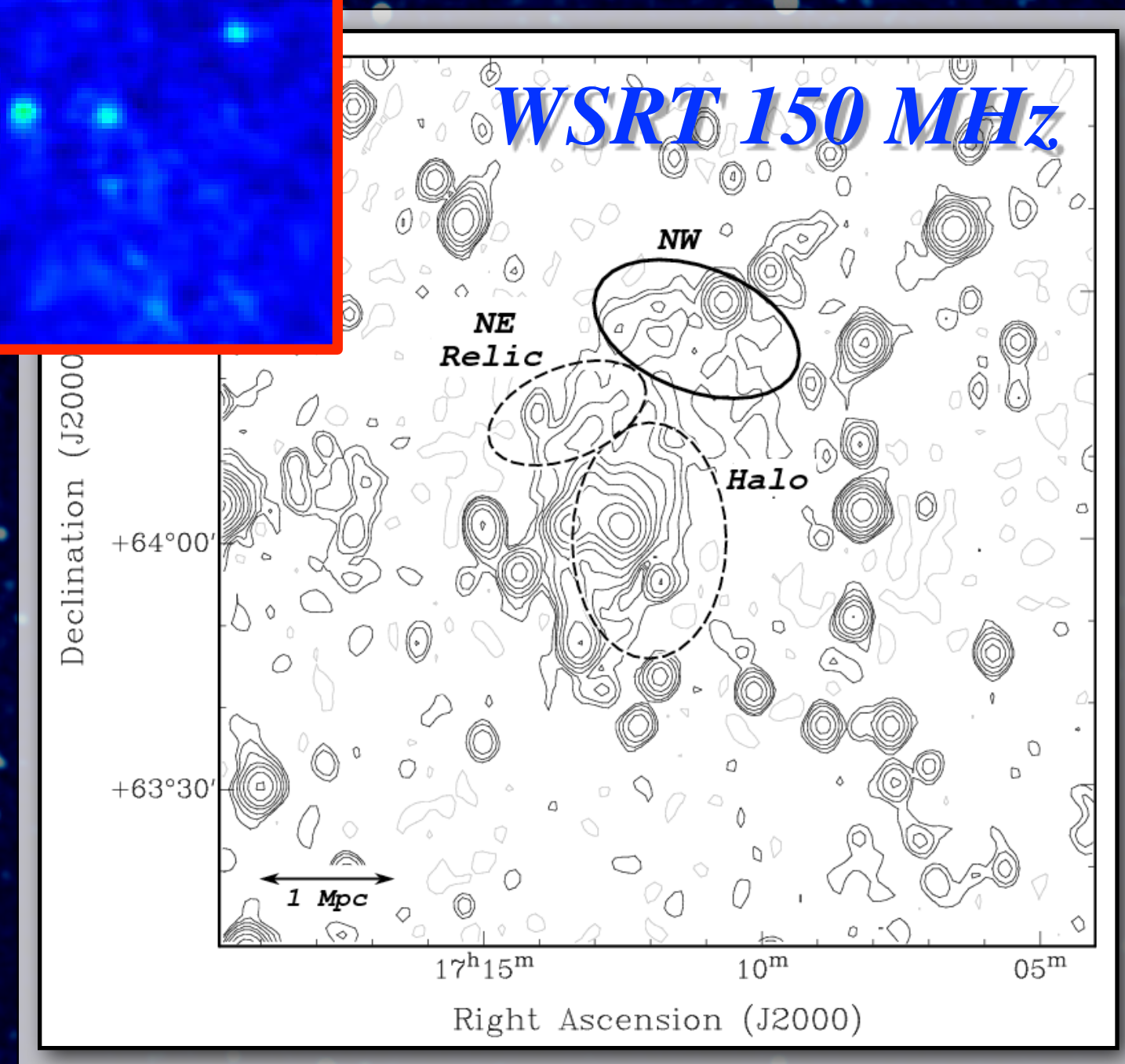
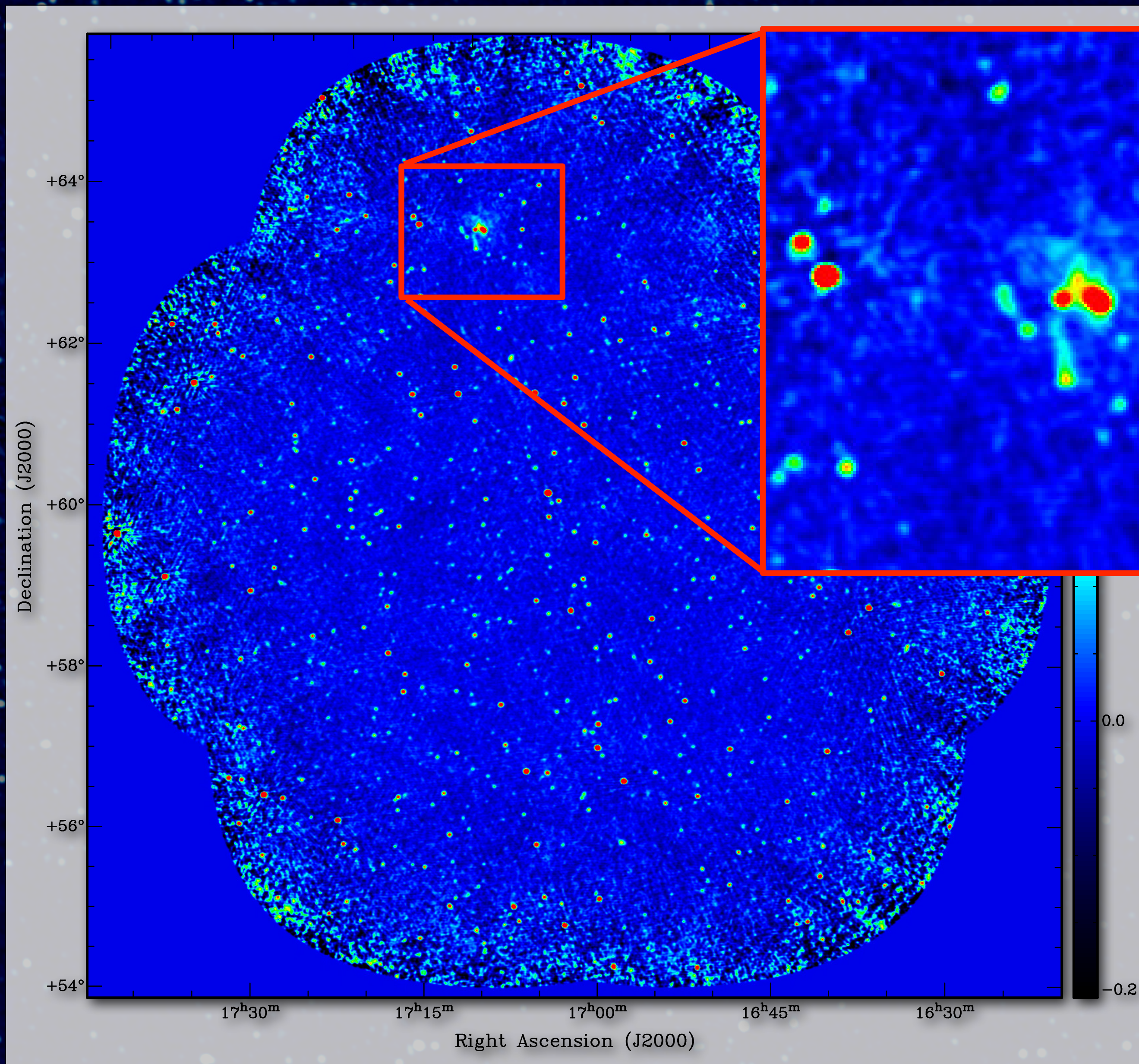
MSSS HBA Mosaic

MSSS Technical Description (Heald et al. in prep.)



- Currently producing MVF mini-catalog for release
- Catalog has ~48 cols. (PS) and 144 cols. (extended)
- 630 sources detected in all 8 bands!

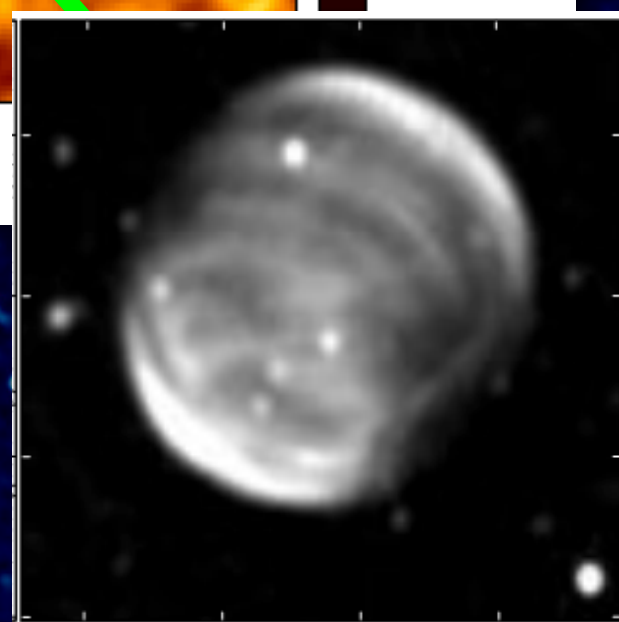
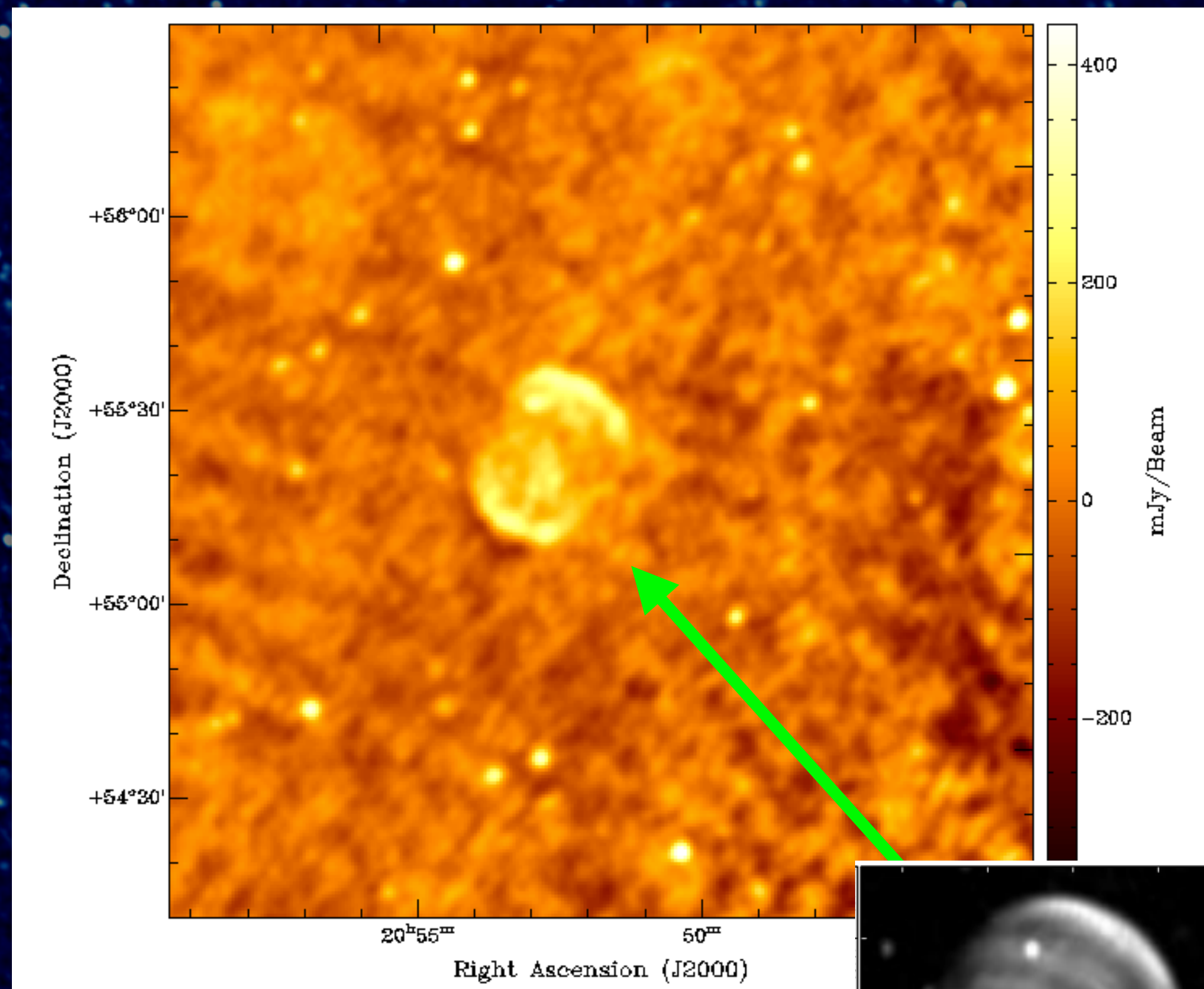
MSSS-HBA: Abell 2255 Field (full 16 MHz)



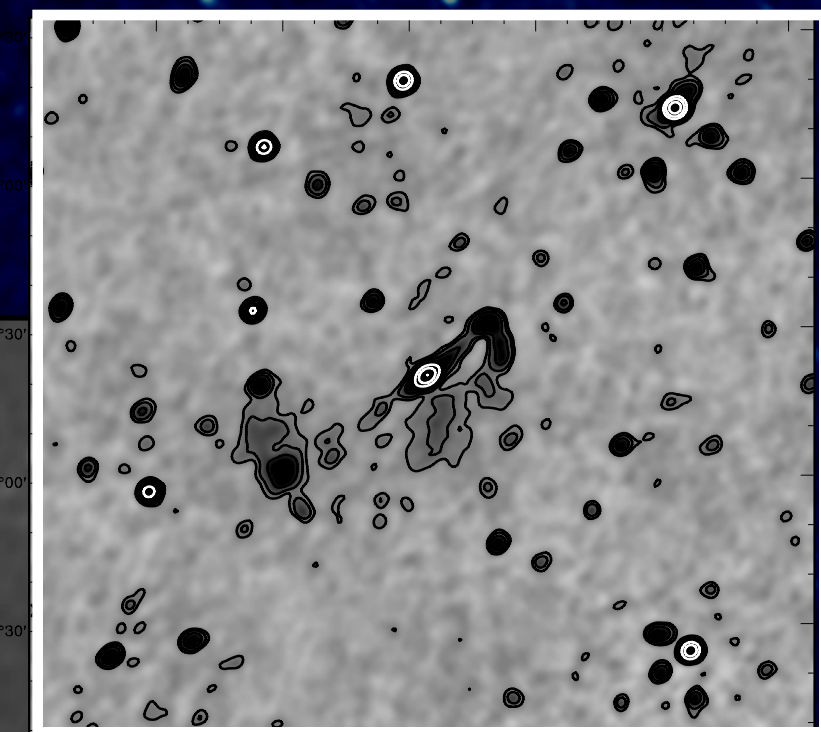
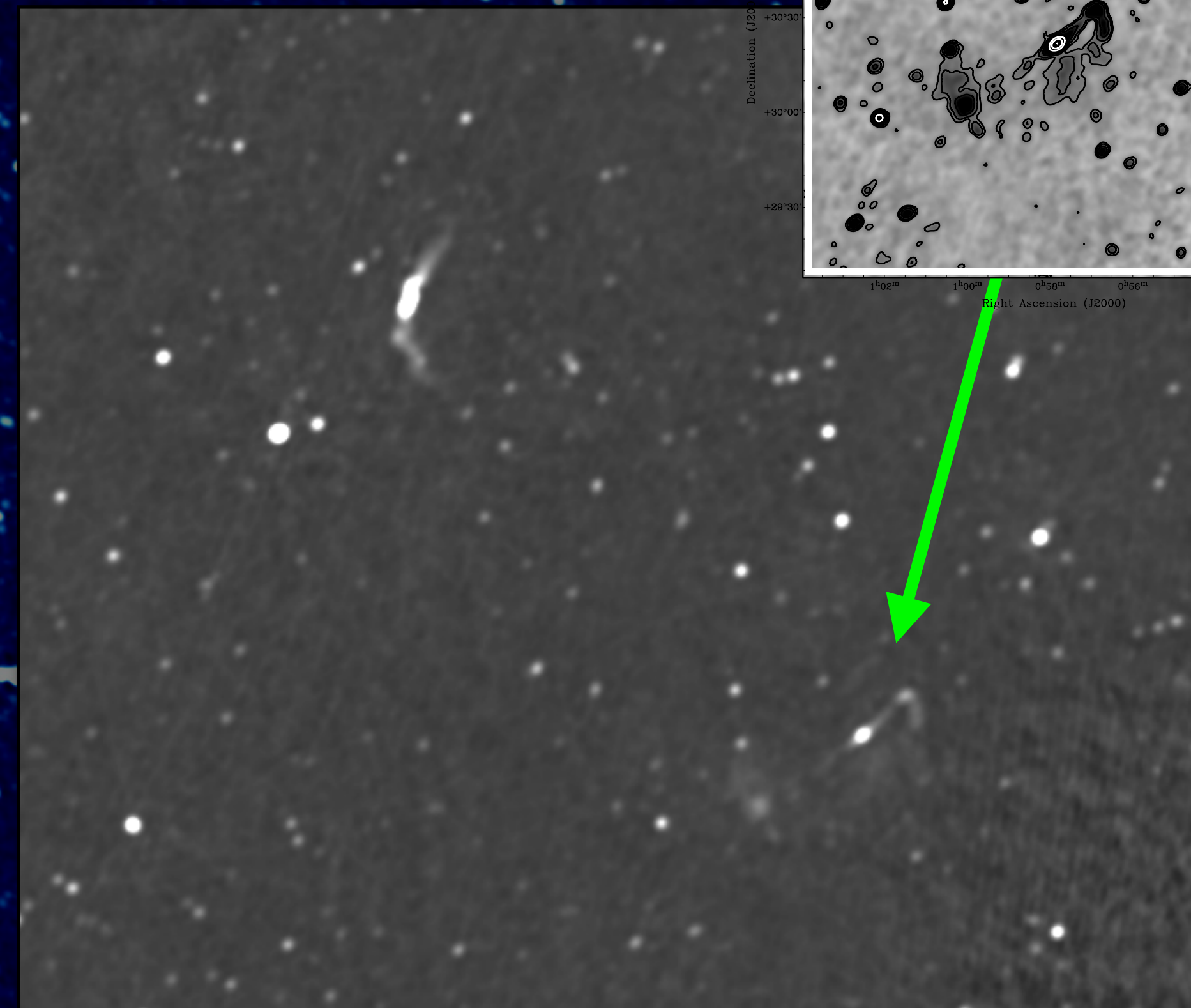
(Pizzo & de Bruyn 2009)

More MSSS early images

Supernova Remnant DA530



(Landecker et al. 1999)



3C31 and NGC 315 in same mosaic

First MSSS(-LBA) transient candidate (Stewart et al, in prep)

Snapshot 1



- Appears in one 11-min snapshot, using 10σ threshold of 4 Jy
- Implied rate for $\Delta t=11\text{min}$ is $1/2537$ transients $\text{day}^{-1} \text{deg}^{-2}$ (~ 1 transient per square degree per 7 years!)

*In MSSS-LBA, 1 subband
always monitoring NCP*

LOFAR Science Drivers

Key Science Projects

Epoch of Reionization

Transients and Pulsars

High Energy Cosmic Rays

Surveys and the Distant Universe

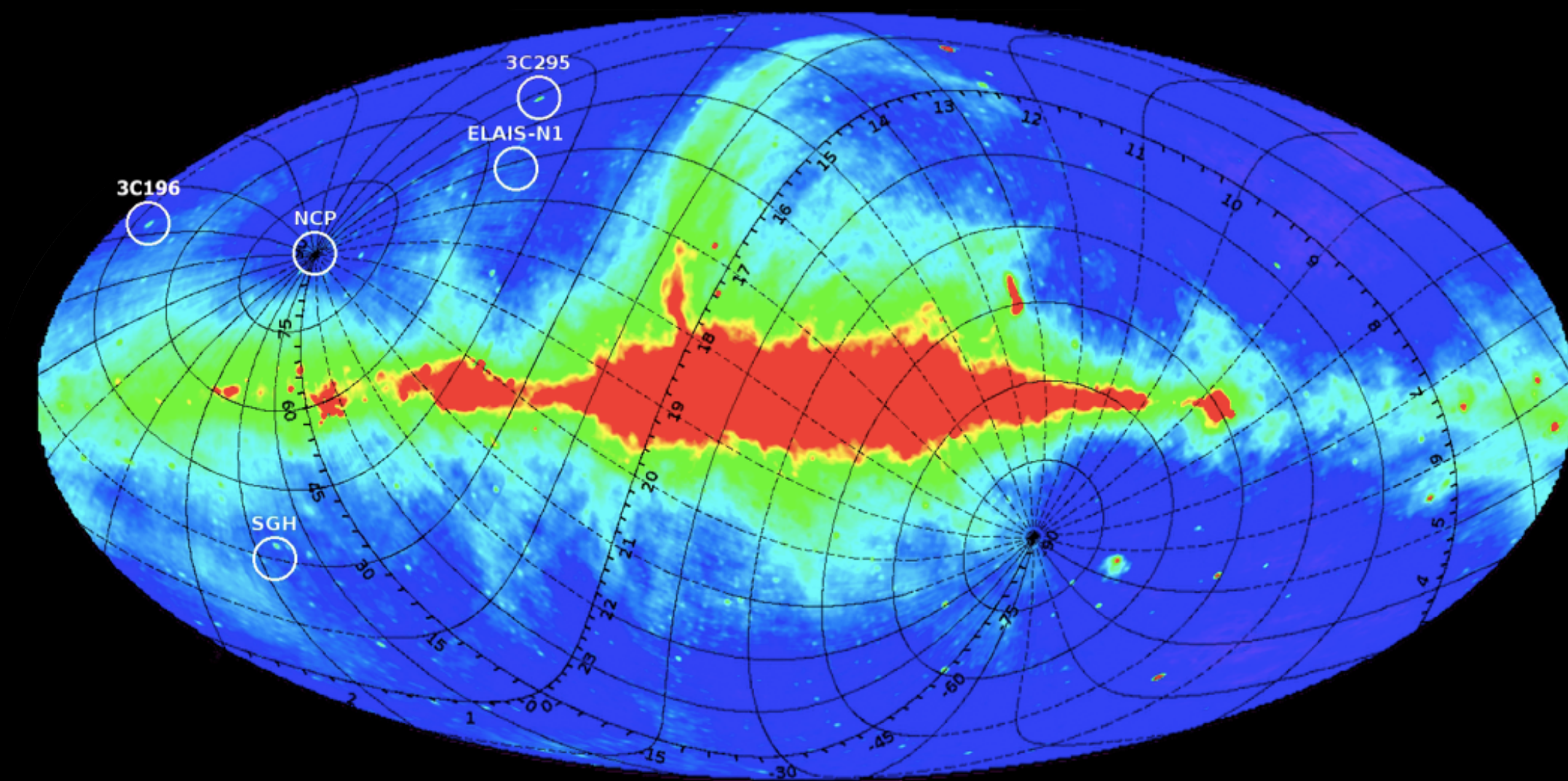
Cosmic Magnetism

Solar Physics and Space Weather

⇒ Large fraction of time to Key Science Projects, 10-20% open skies

KSPs have reserved access time in exchange for contributing software, expertise, commissioning, etc.

KSP membership not limited to member states, expertise-based

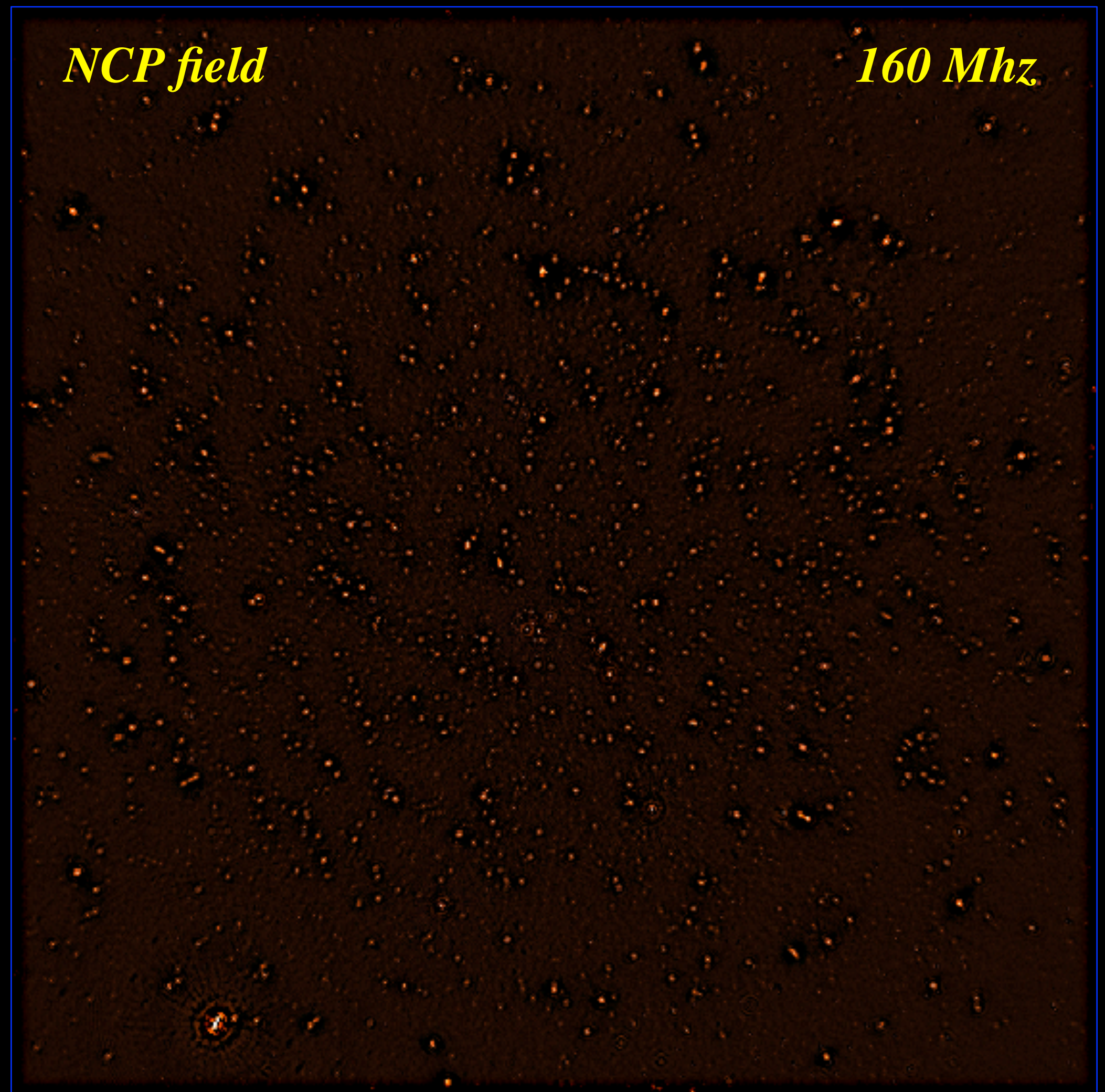


- Total 17 observations, 170 hours
- Concentrating on 3 distinct fields
- Custom processing on EoR cluster

$$\sigma \sim 30 \mu\text{Jy} \quad \theta \sim 6''$$

70 hrs, 96 MHz bandwidth

8° x 8°, 15000x15000 pixels, 2'' pixels

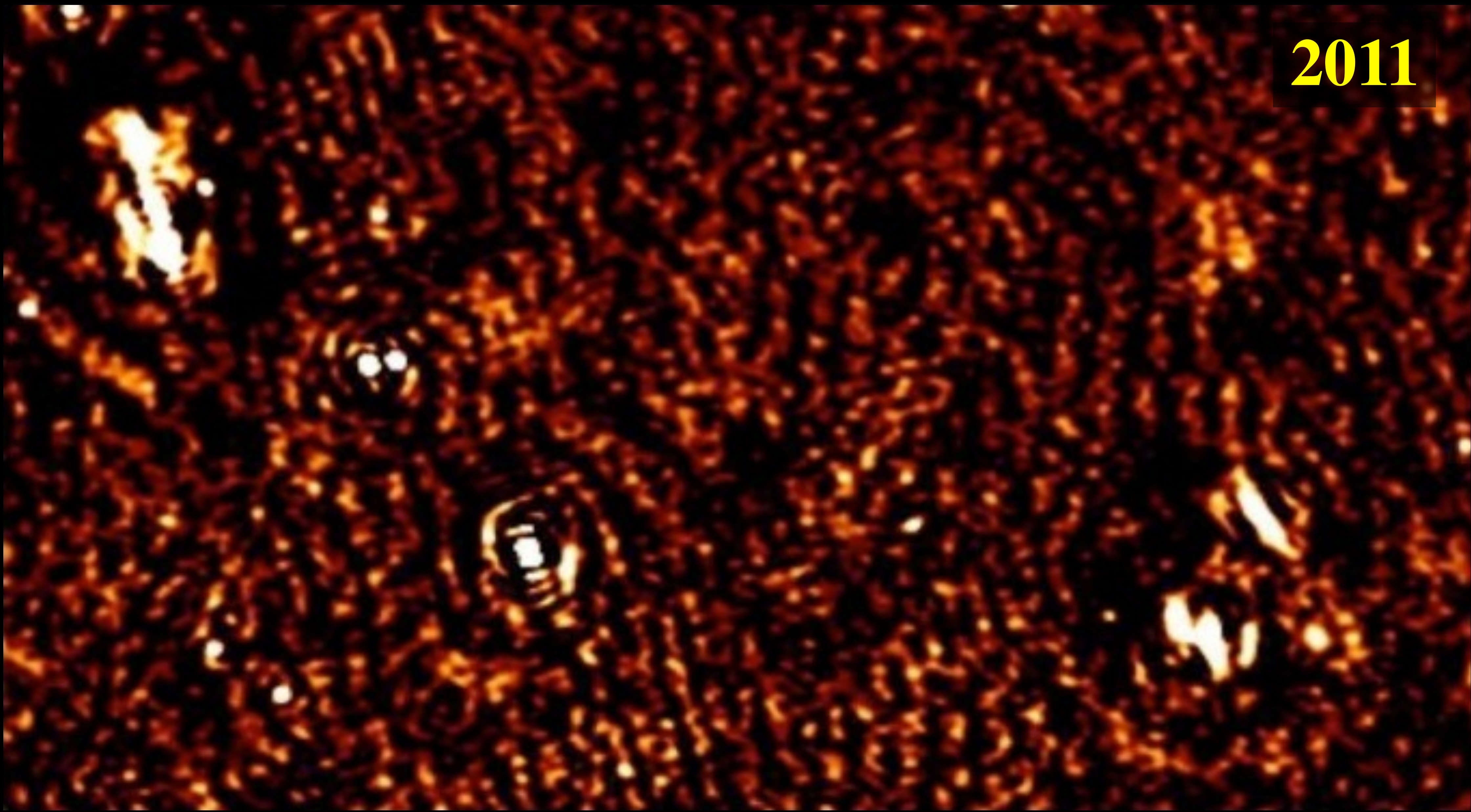


(courtesy S. Yatawatta and the EoR KSP Team)

NCP field $\approx 180 \mu\text{Jy} / \text{beam}$

(image courtesy S. Yatawatta)

2011



NCP field $\approx 30 \mu\text{Jy} / \text{beam}$

(image courtesy S. Yatawatta)

2013



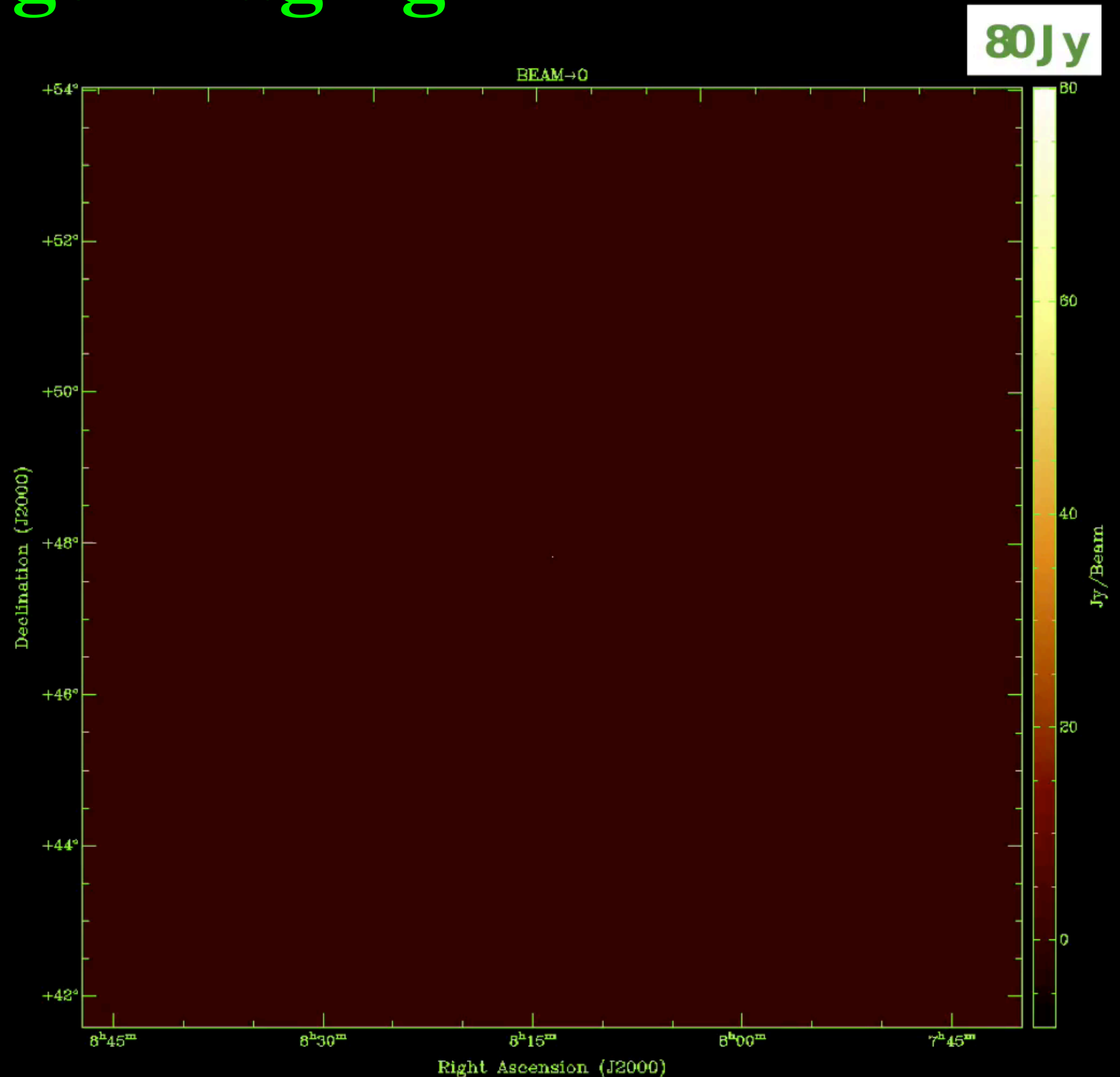
High Dynamic Range Imaging

(images courtesy V. Pandey)

3C196 field

160 MHz, 32 hrs, 96 MHz bandwidth

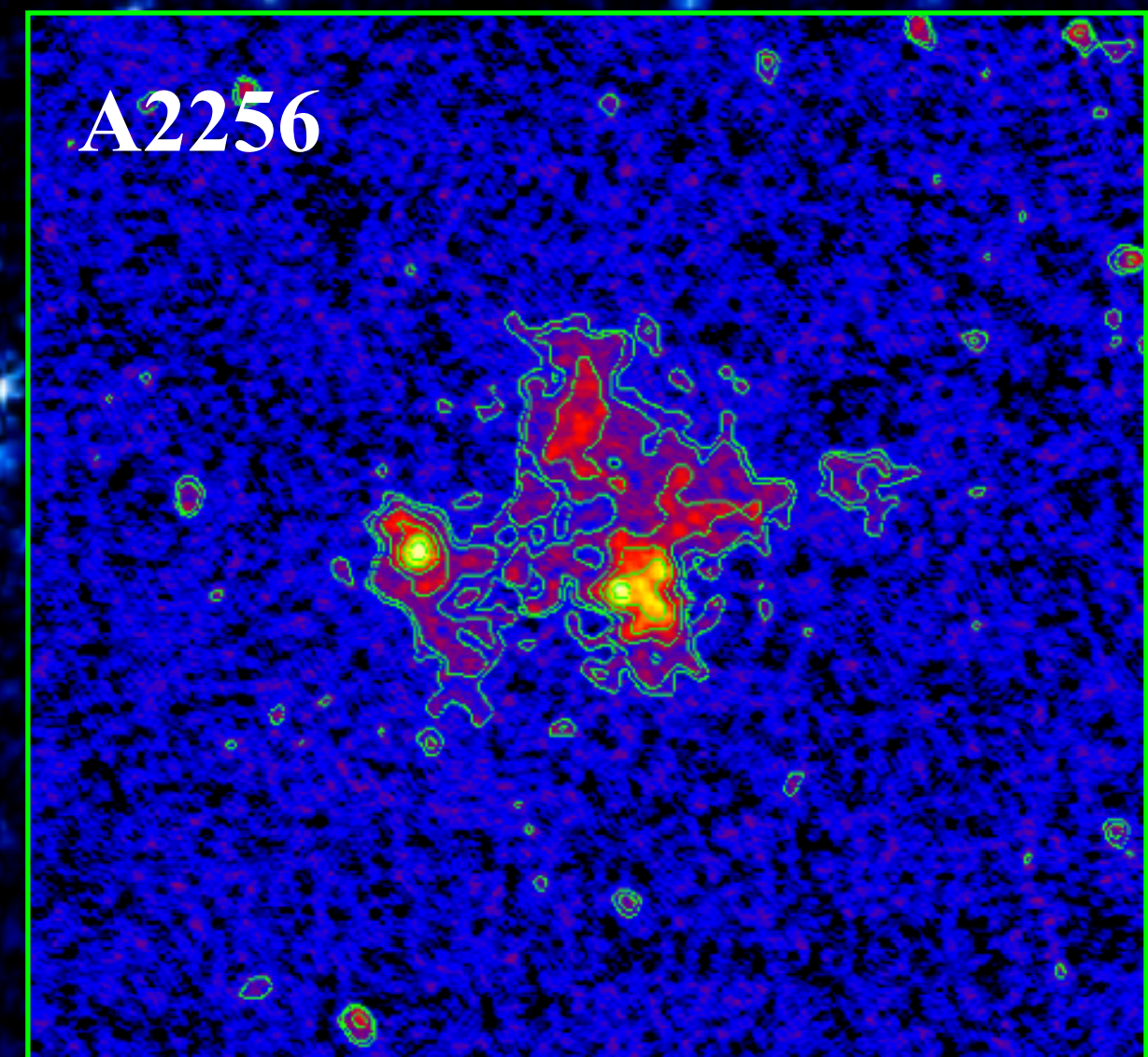
DR ~ 1,000,000:1!



Cluster Radio Halos and Relics

- Increase the sample size of halos and relics
- Constrain re-acceleration models
- Perform merger calorimetry

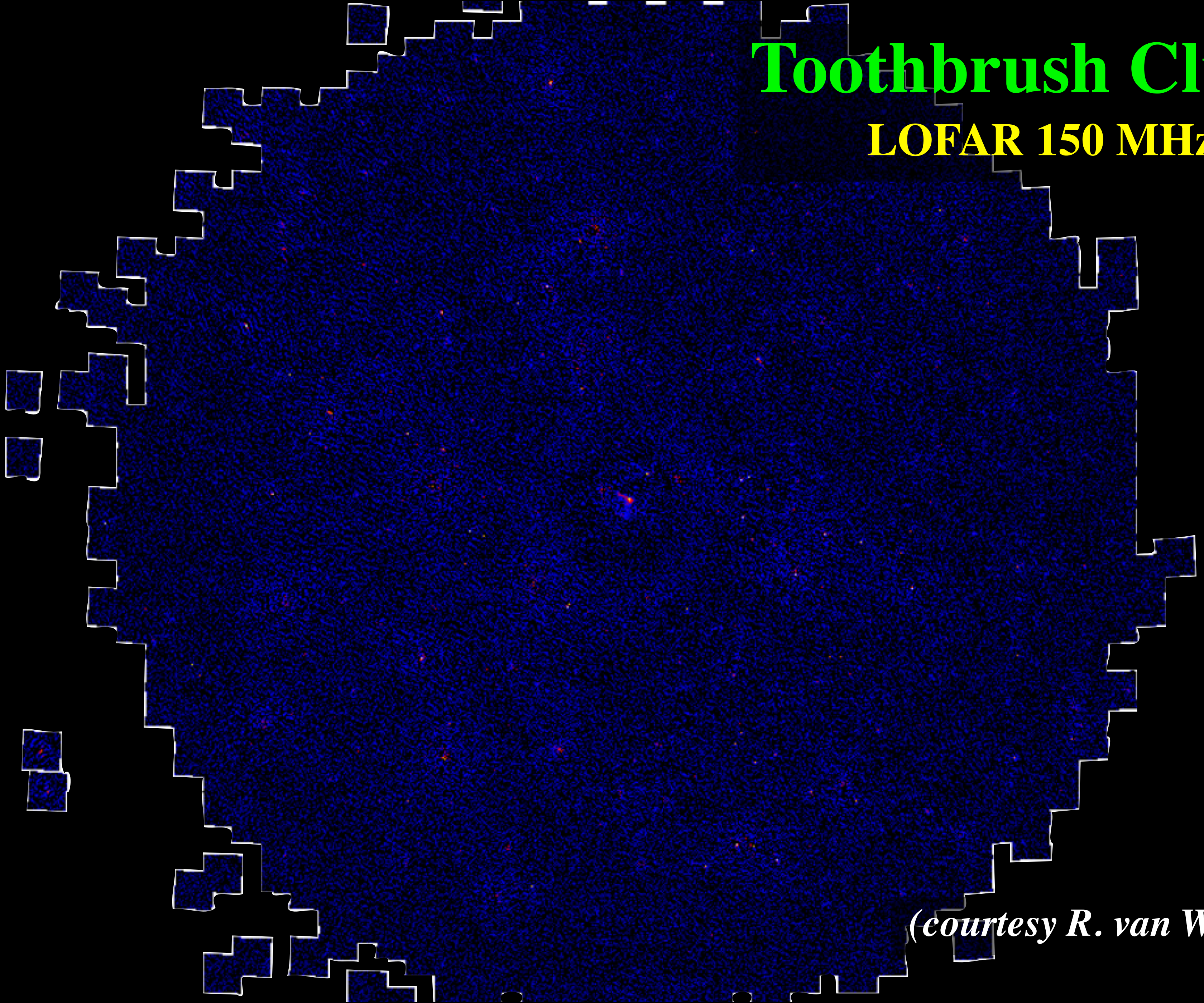
The Toothbrush Cluster (van Weeren et al. in prep.)



(van Weeren et al. 2011)

Toothbrush Cluster

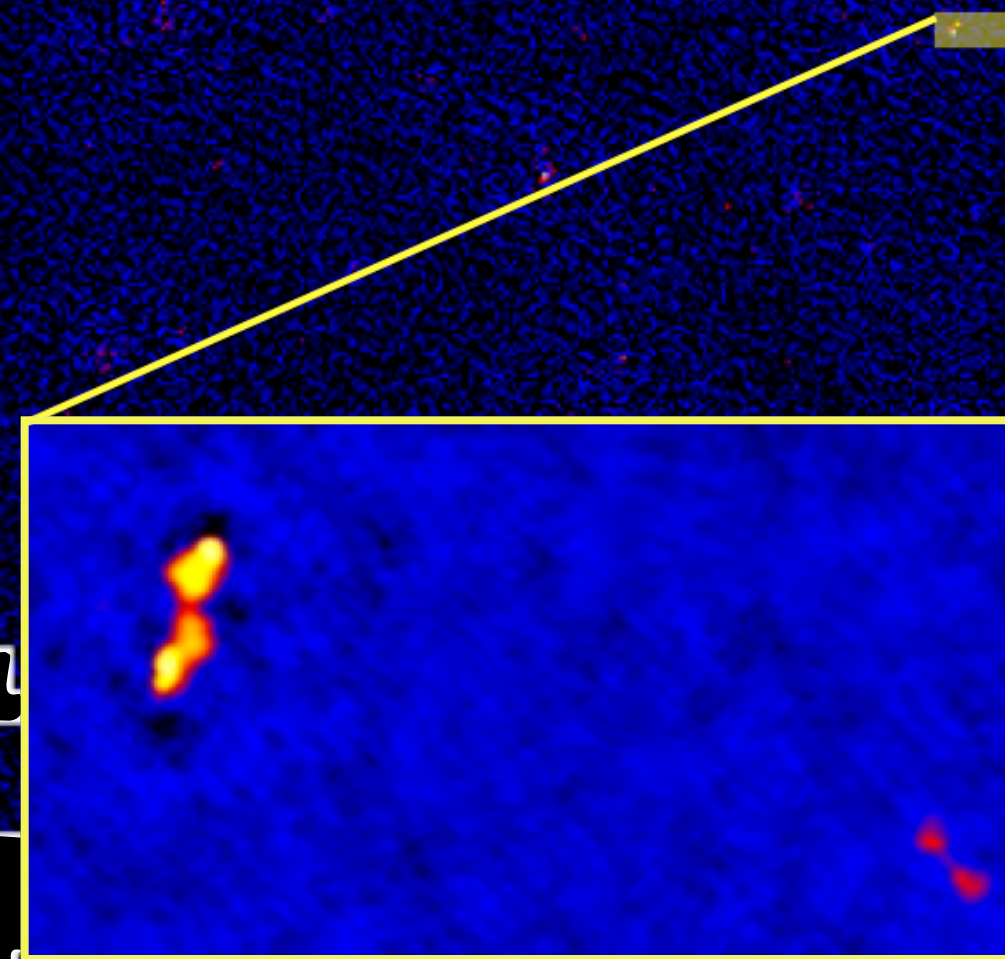
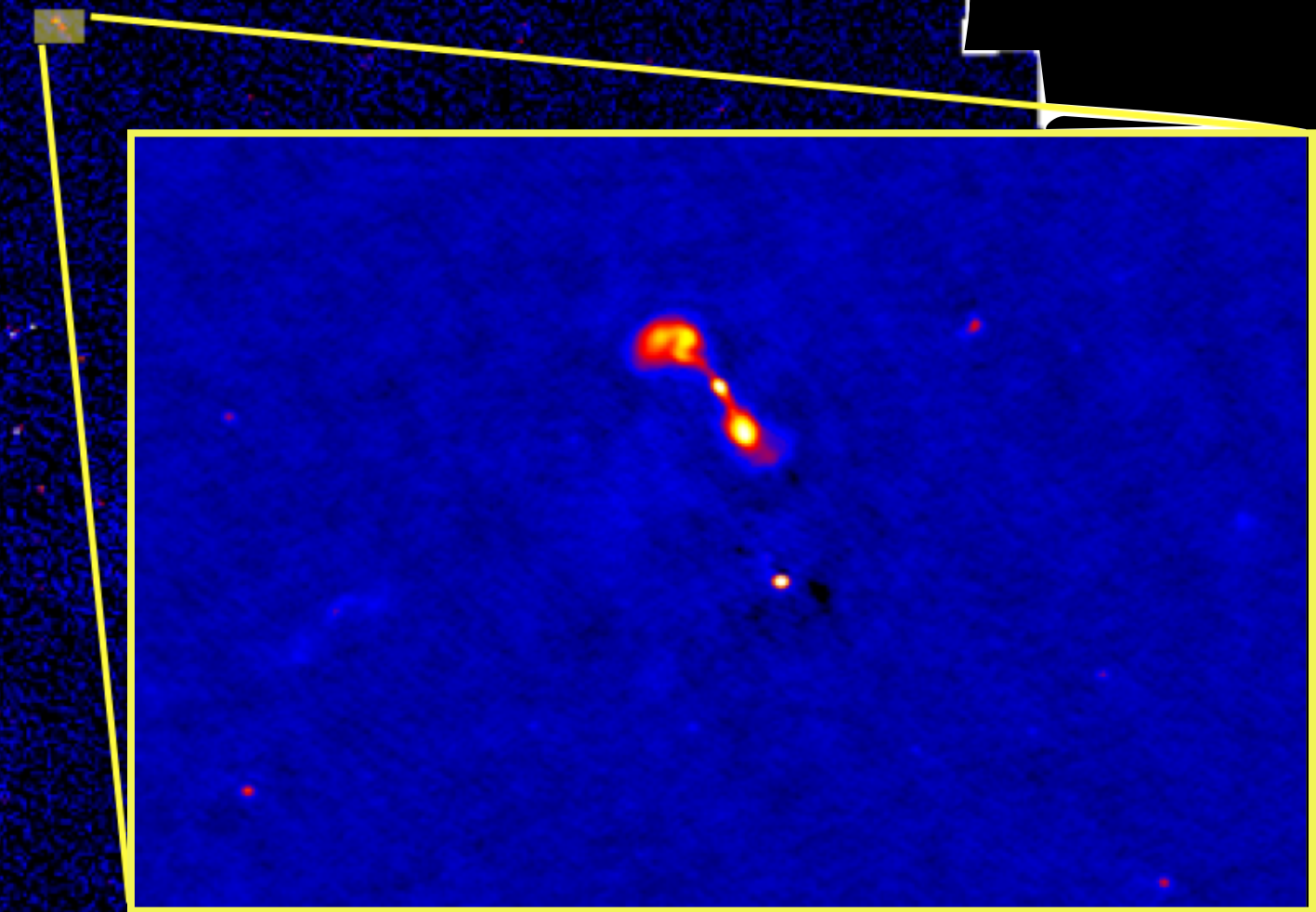
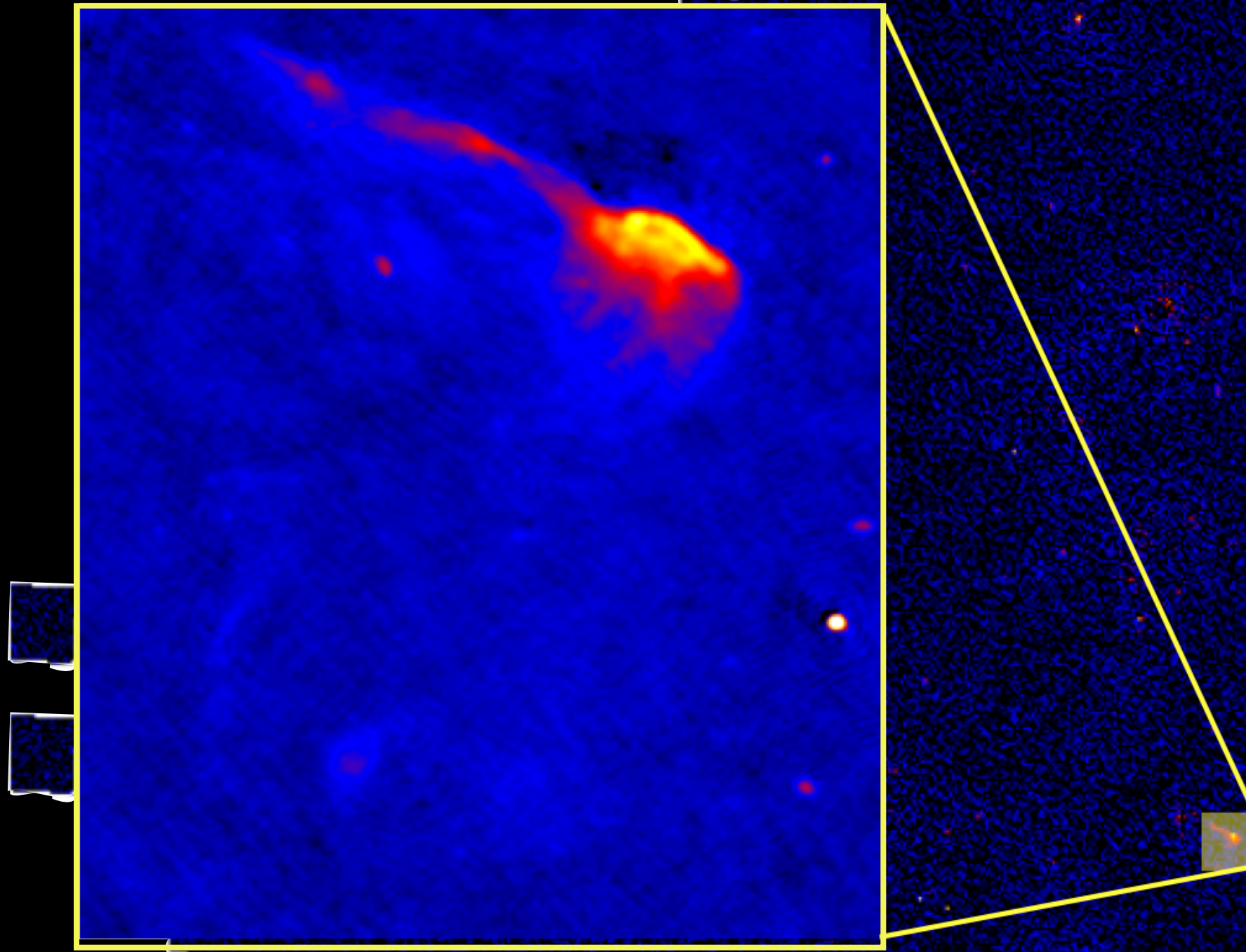
LOFAR 150 MHz



(courtesy R. van Weeren)

Toothbrush Cluster

LOFAR 150 MHz



(courtesy R. van Weeren)

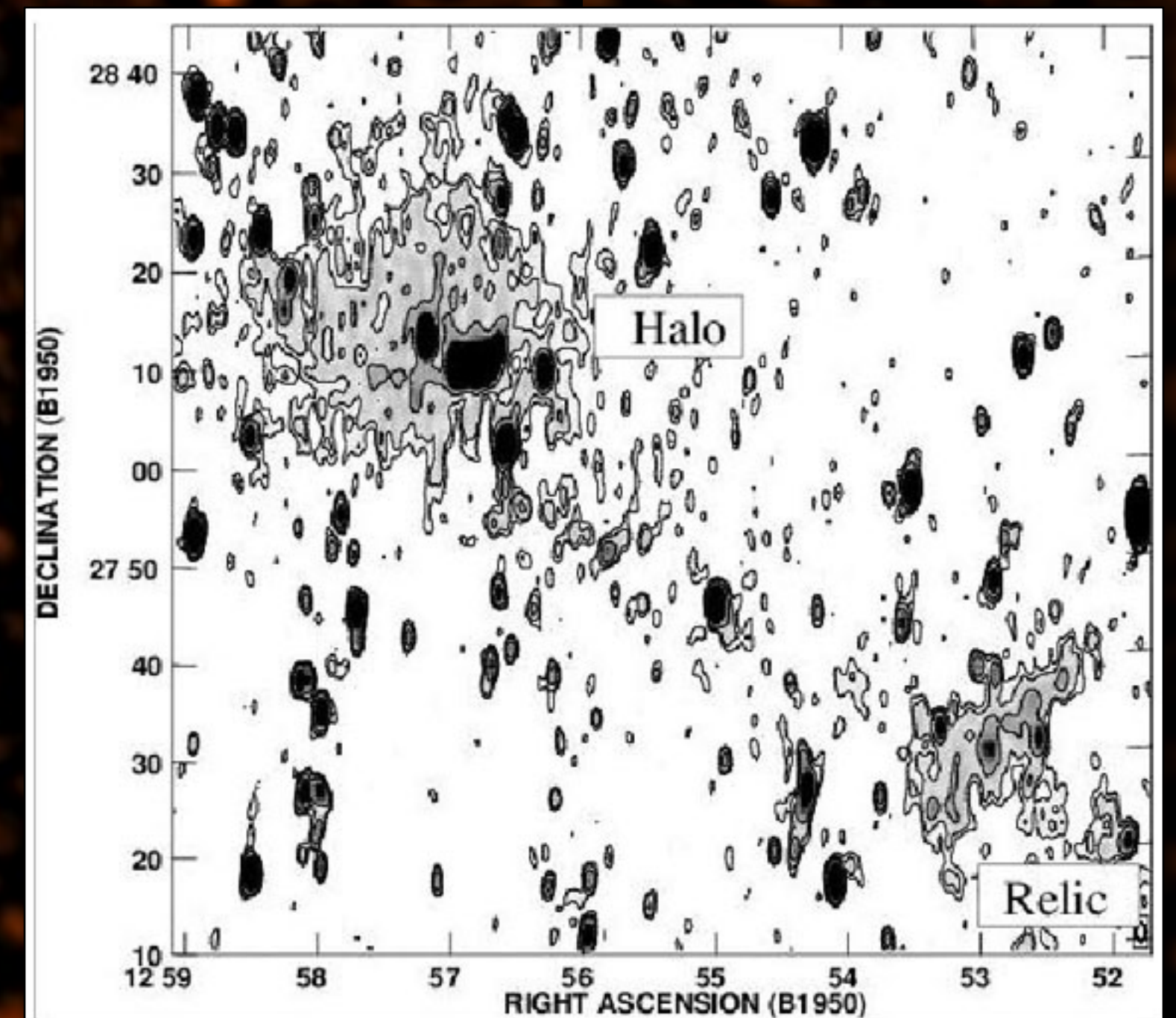
Halos and Relics in the Coma Cluster

LOFAR 140 MHz

Halo

Relic

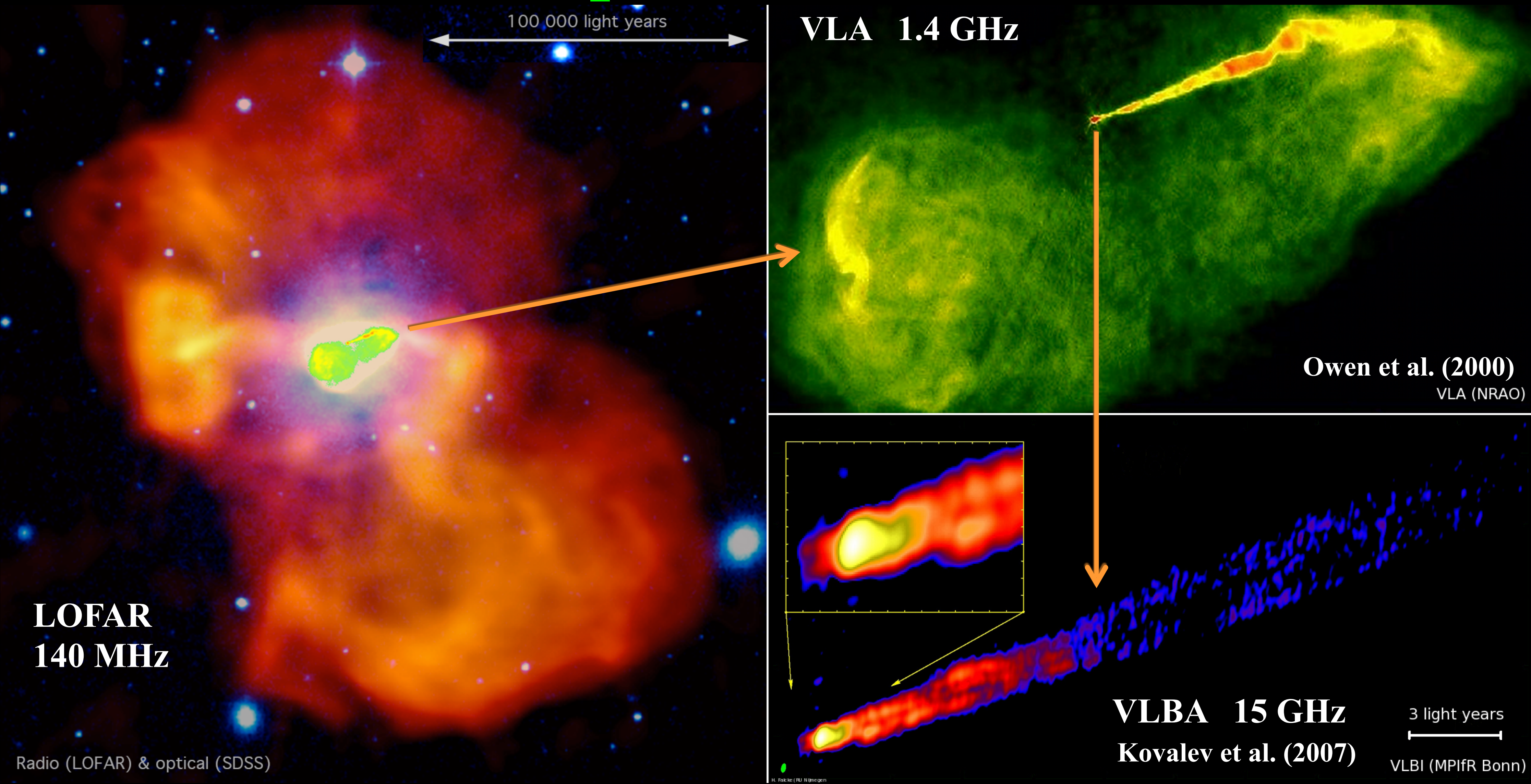
WSRT 333 MHz



Bonafede et al. (in prep.)

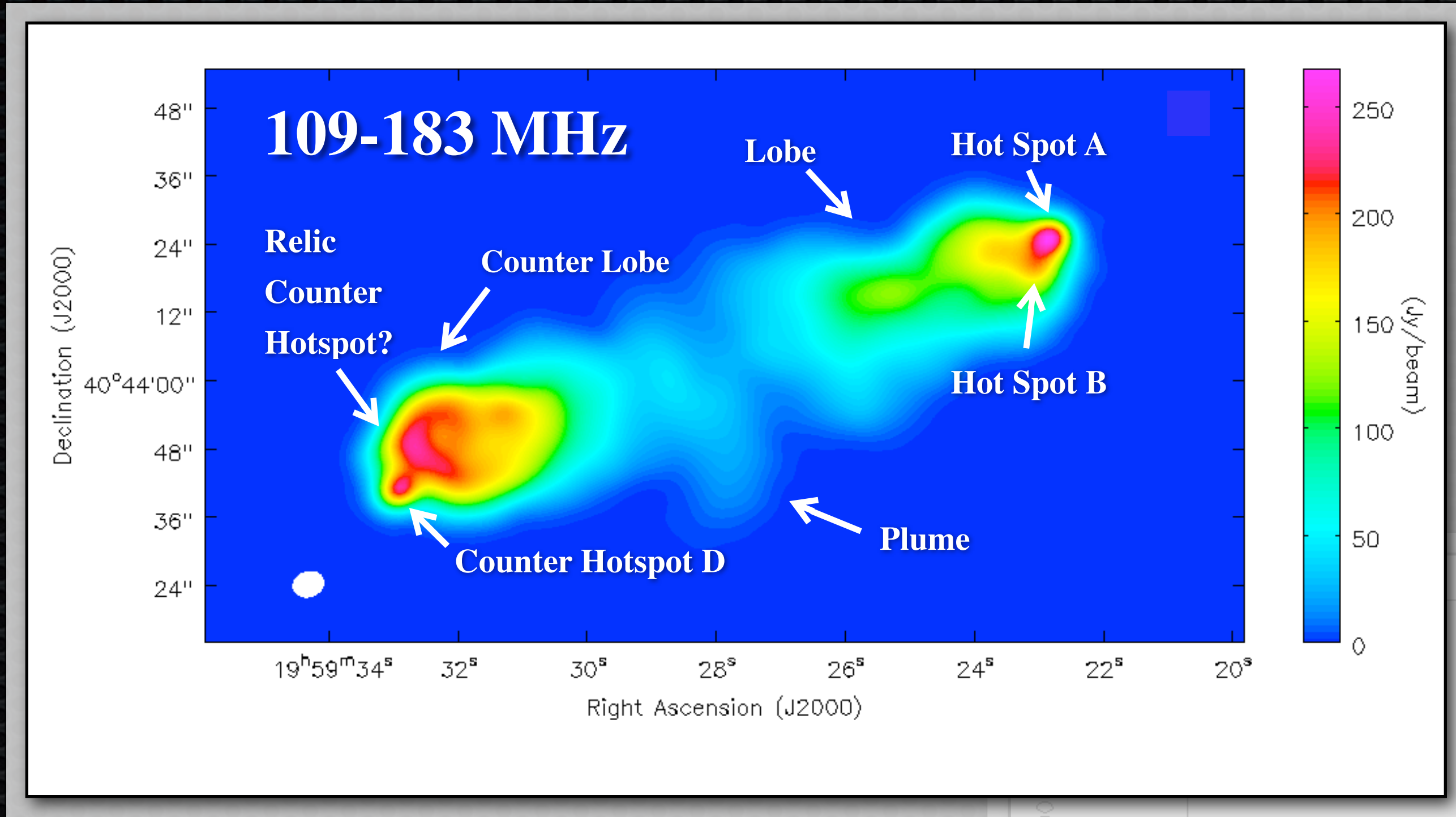
Giovannini et al. (1993)

M87 at Low Frequencies



Need extra pressure in the bubbles (protons, non-equip.) ...

Cygnus A in the Low-Frequency Radio

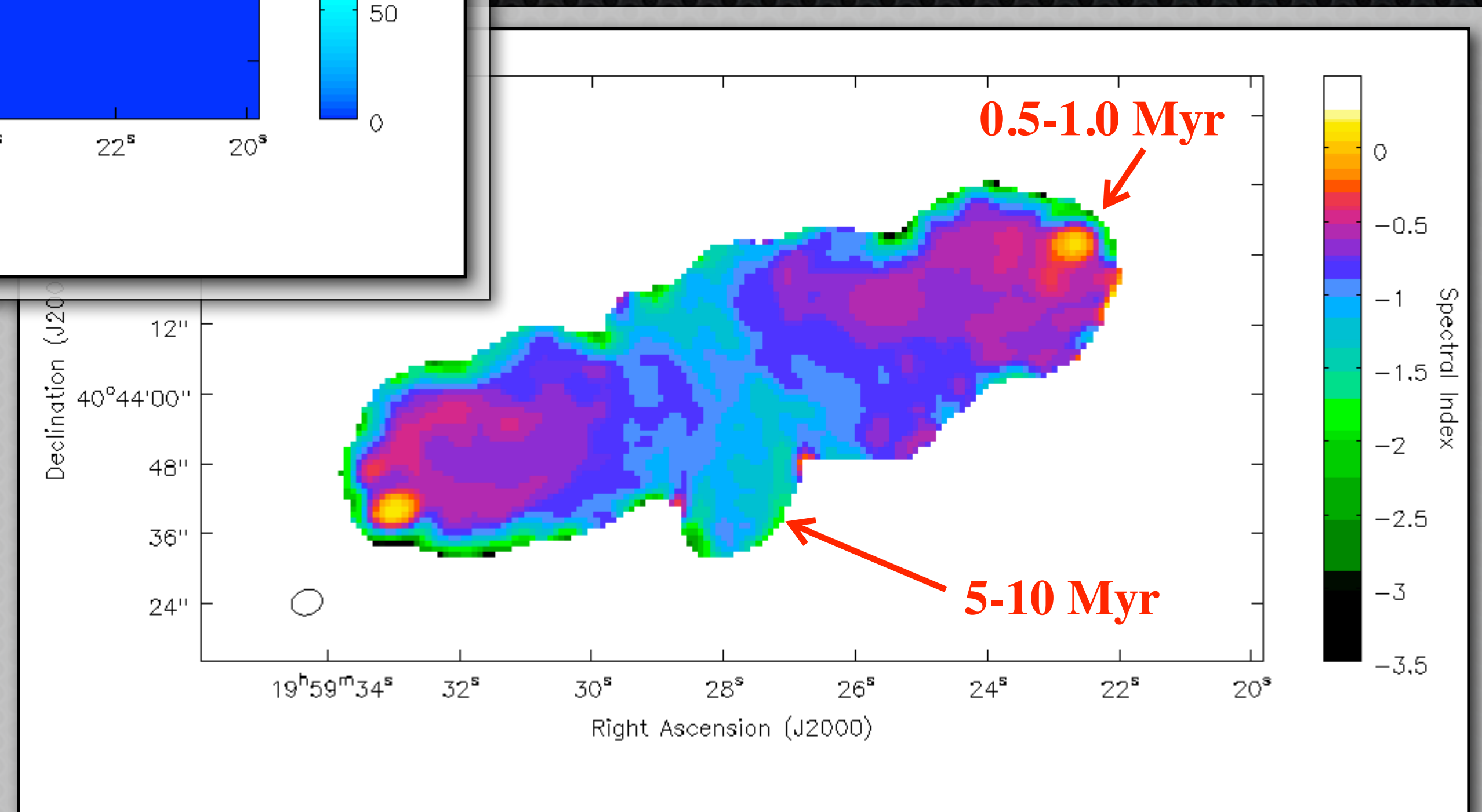


Spectral aging analysis consistent with higher frequency (Carilli et al. 1991)

No evidence for extended diffuse emission beyond shock (yet!)

No diffusion of plasma to large radii

Spectral index map



McKean et al. (2014)

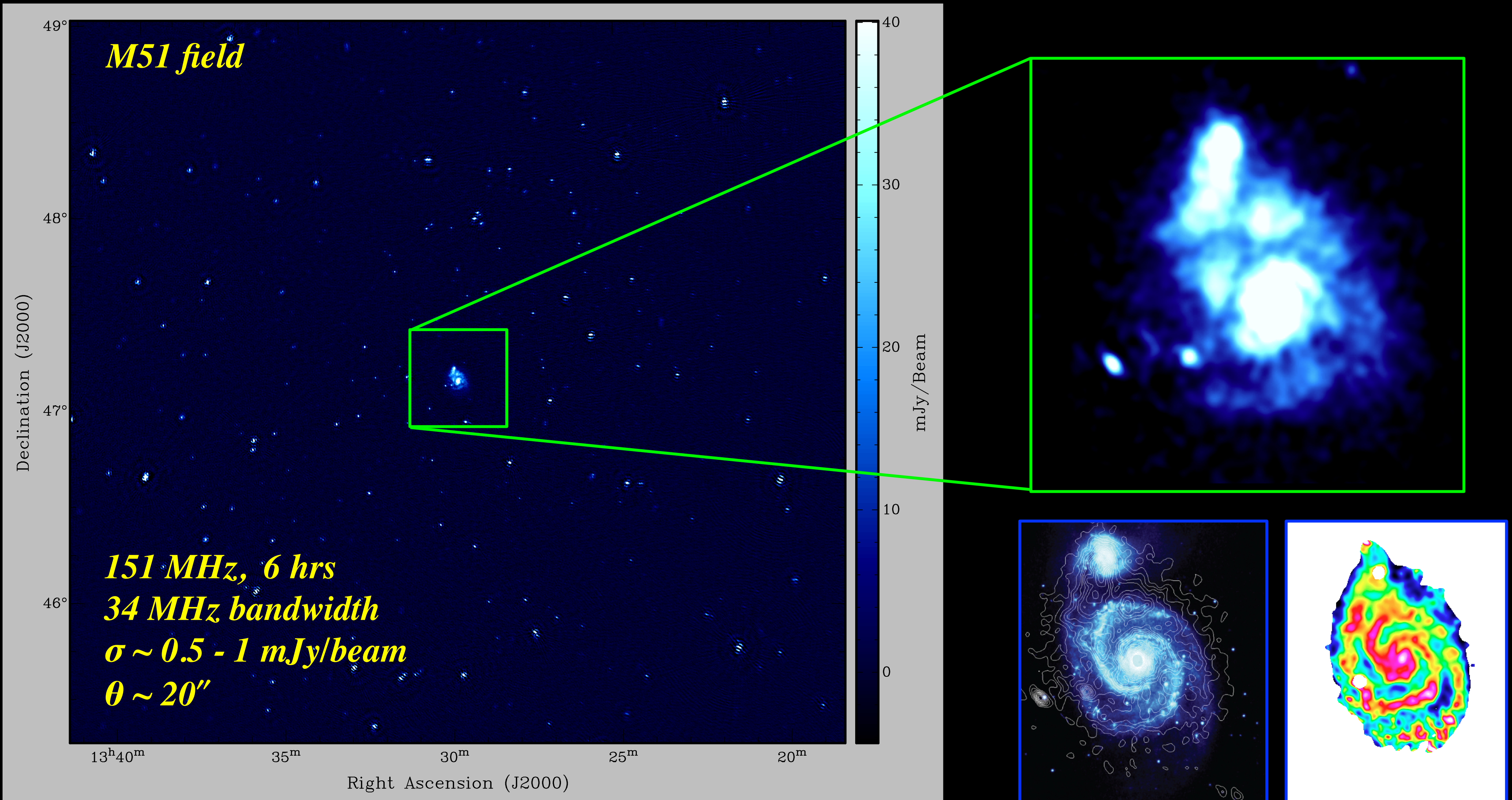
LOFAR HBA

6 hr / 109 - 183 MHz / 28 MHz

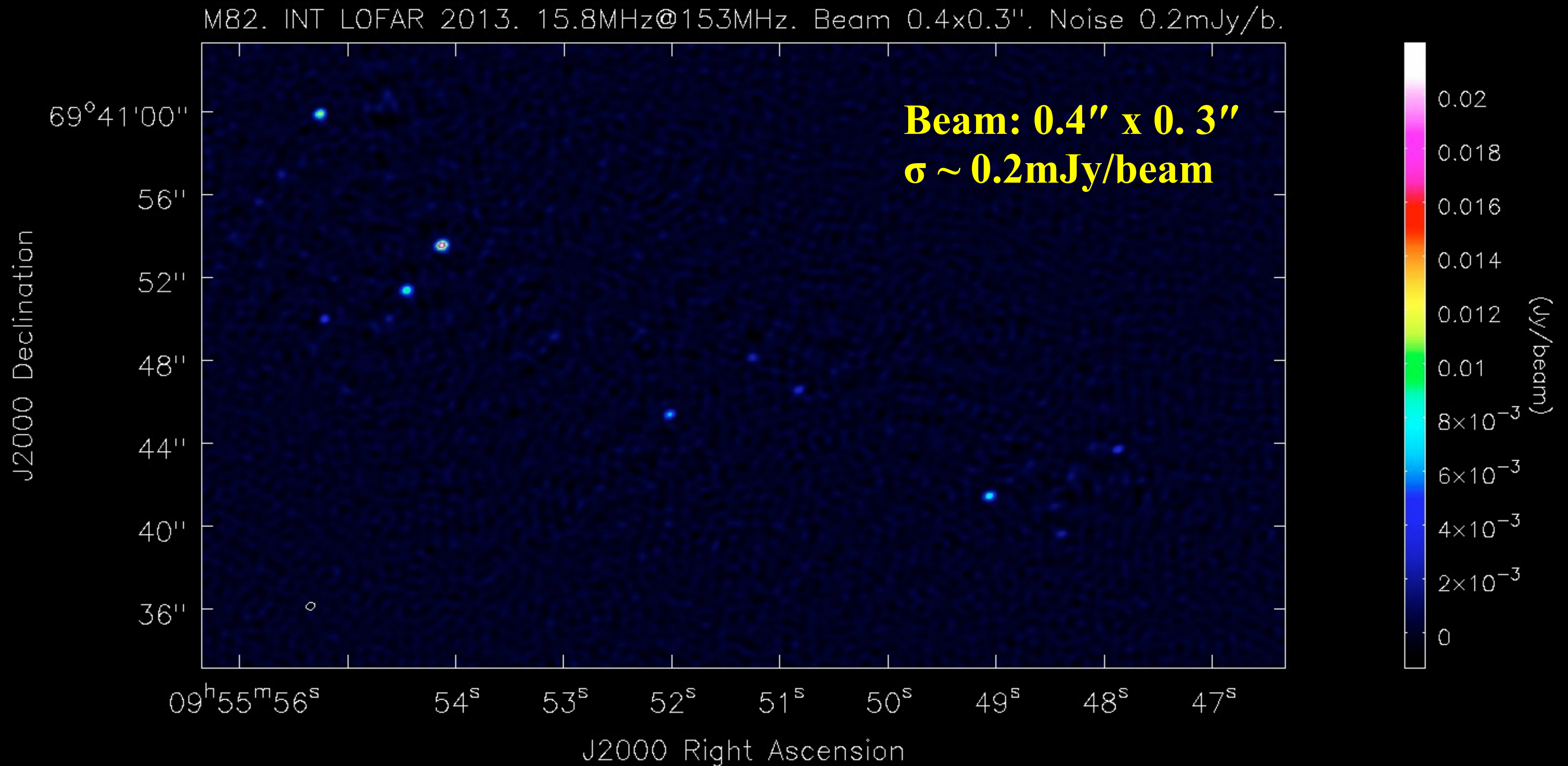
$\sigma \sim 43$ mJy / DR ~ 5000

NL baselines only

3.8 x 2.7 arcsec beam

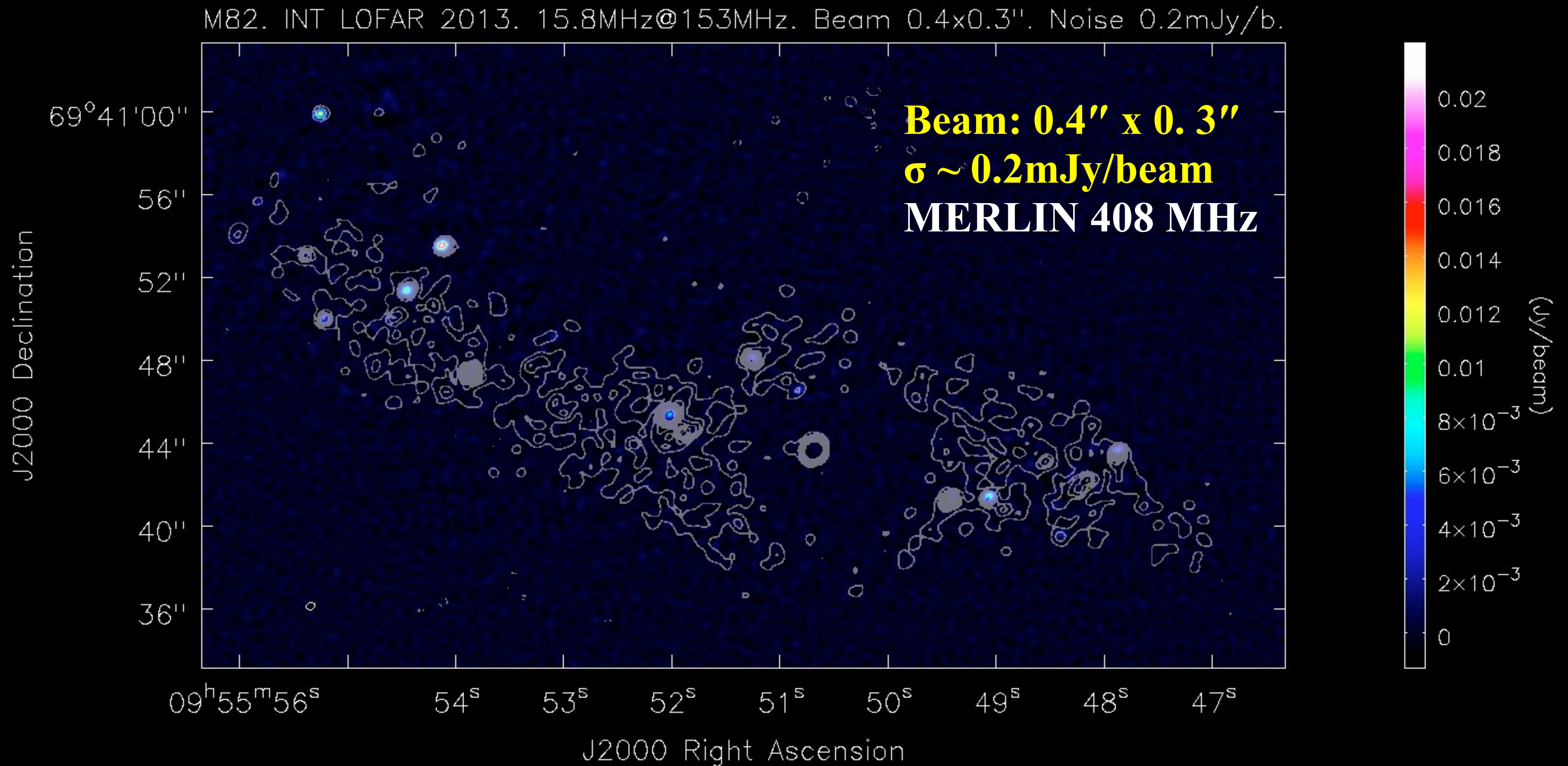


M82 with International Baselines



(Varenius, Conway, et al. 2014, in prep.)

M82 with International Baselines



(Varenius, Conway, et al. 2014, in prep.)

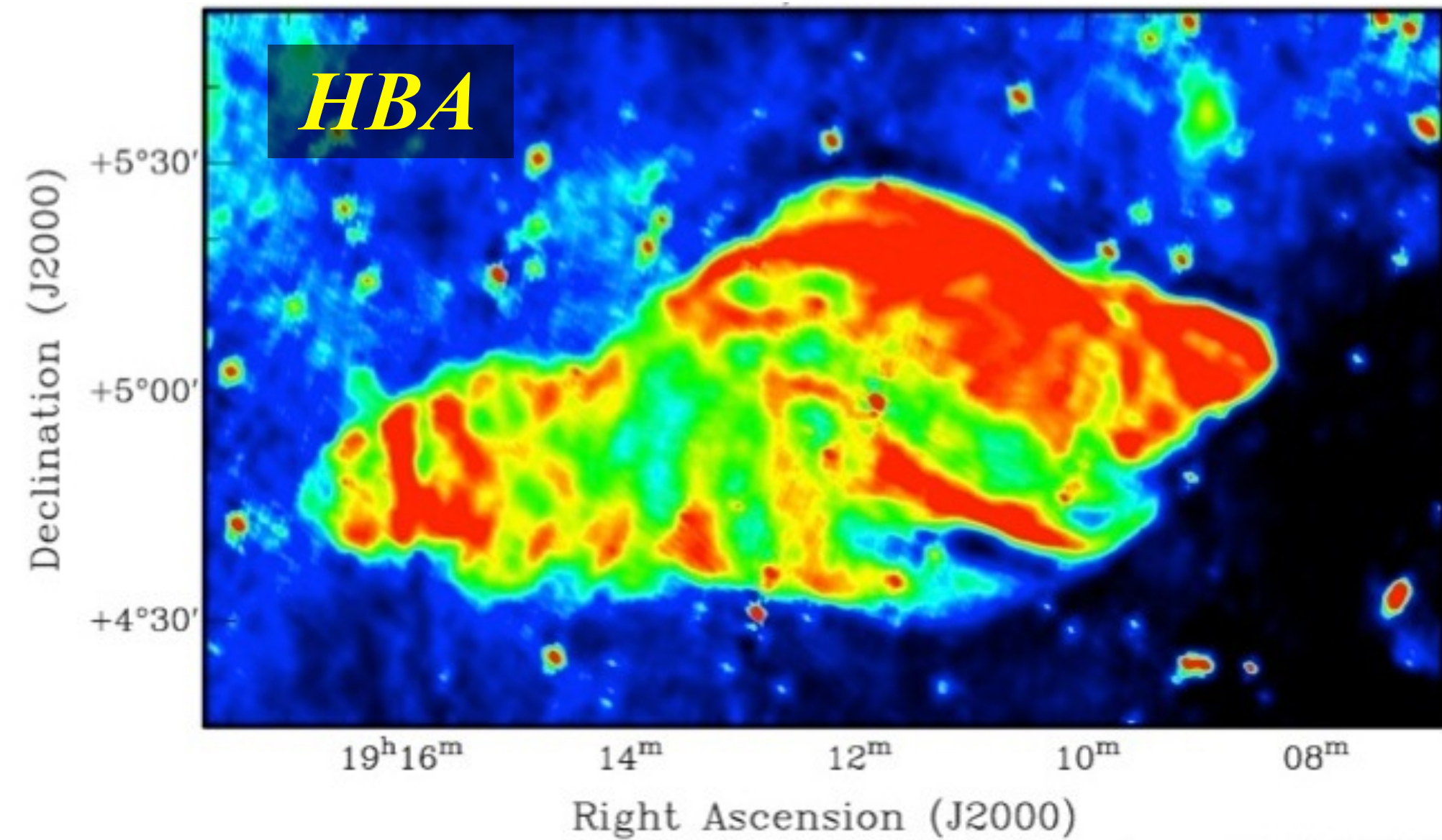
SS433/W50

X-ray binary jet interacting with SNR

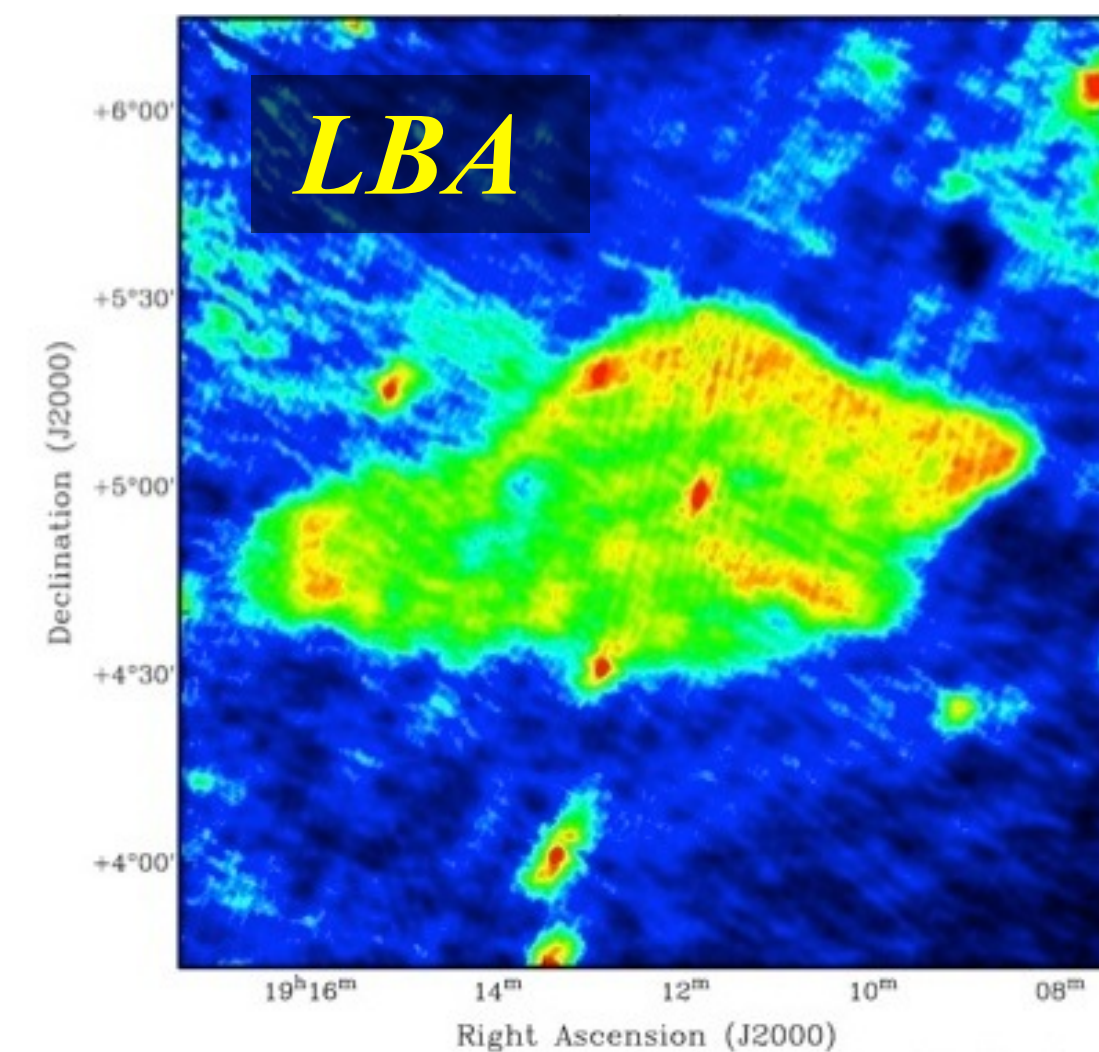
Galactic Plane

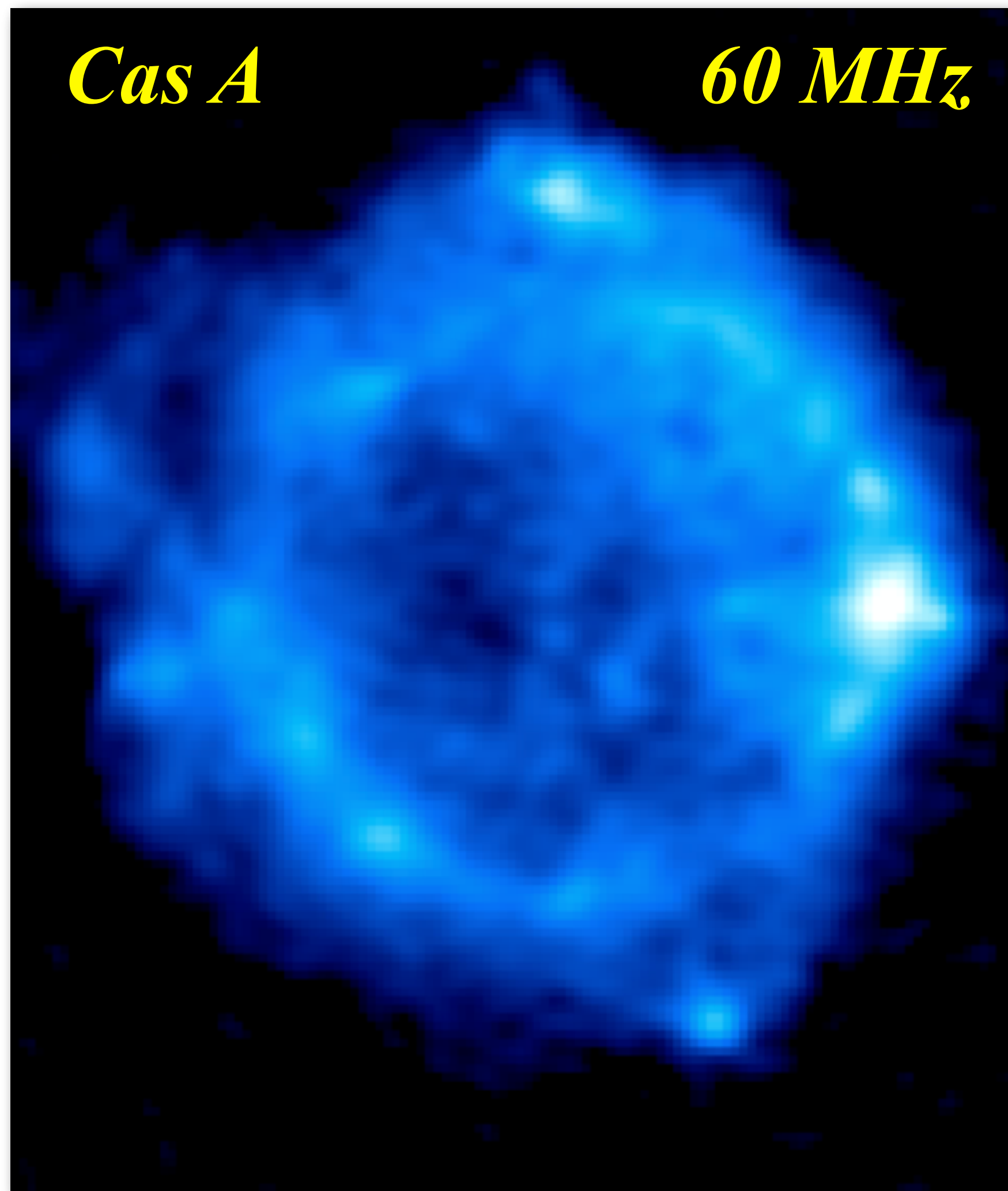
New SNR?

(Broderick, Miller-Jones, et al. 2014)



- 4h, 48 MHz bw
- 115-163 MHz
- <12km baseline
- 62" x 42"
- $\sigma \sim 8$ mJy/beam

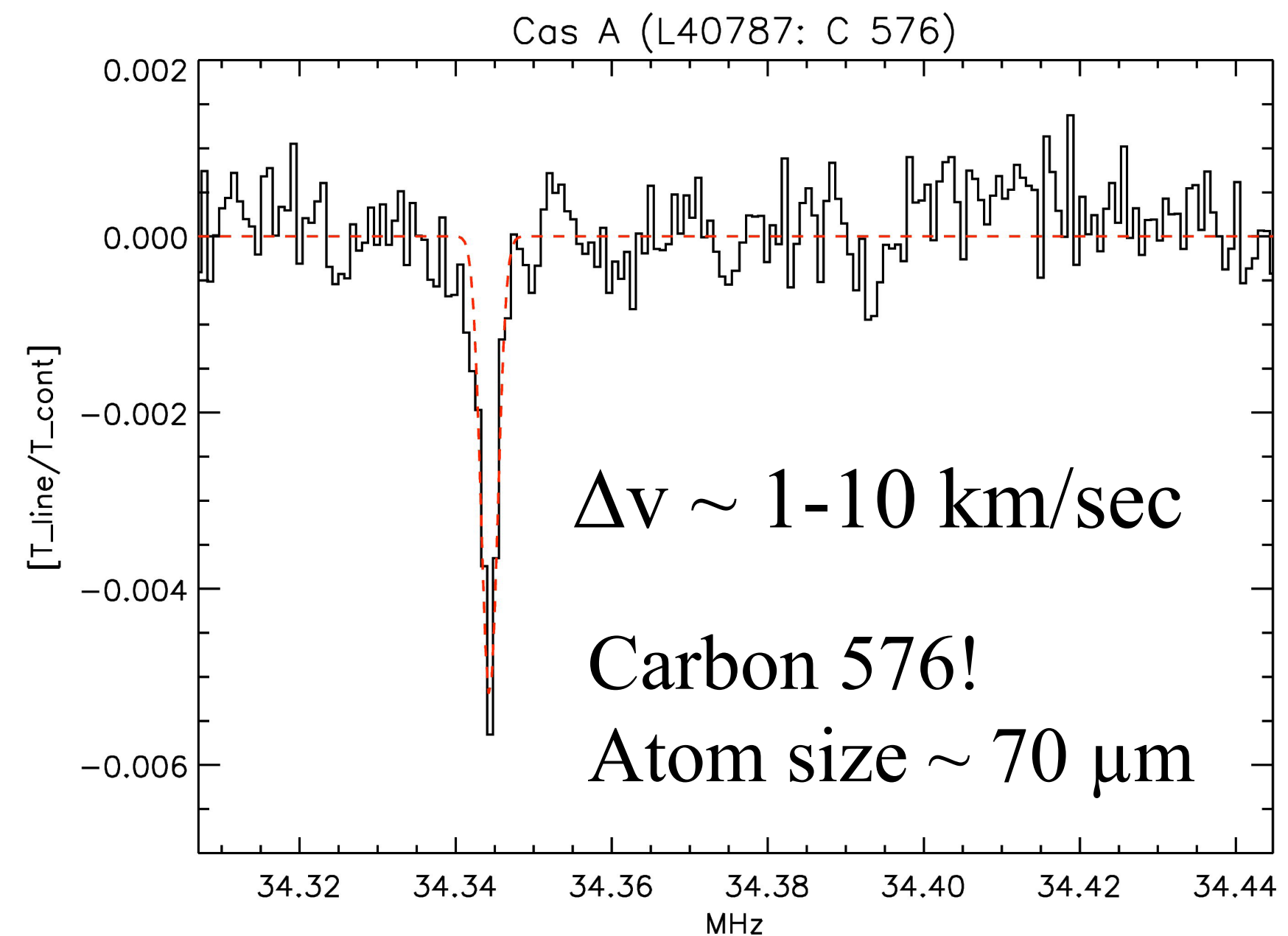




(van Weeren et al. 2014)

RRLs probe the Cold Neutral Medium (CNM)

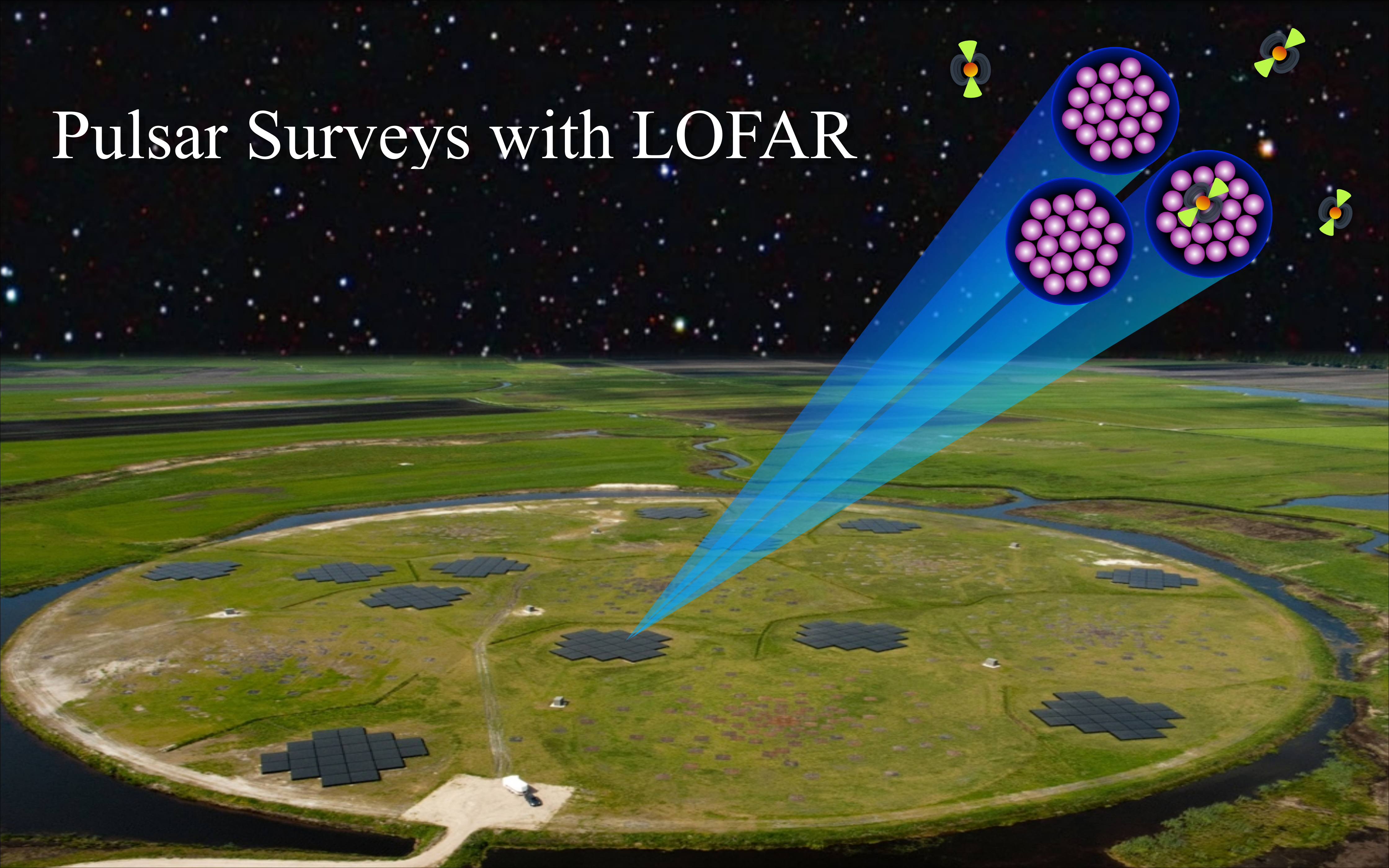
LOFAR spectrum towards Cas A



(Asgekar, Oonk, et al. 2013)

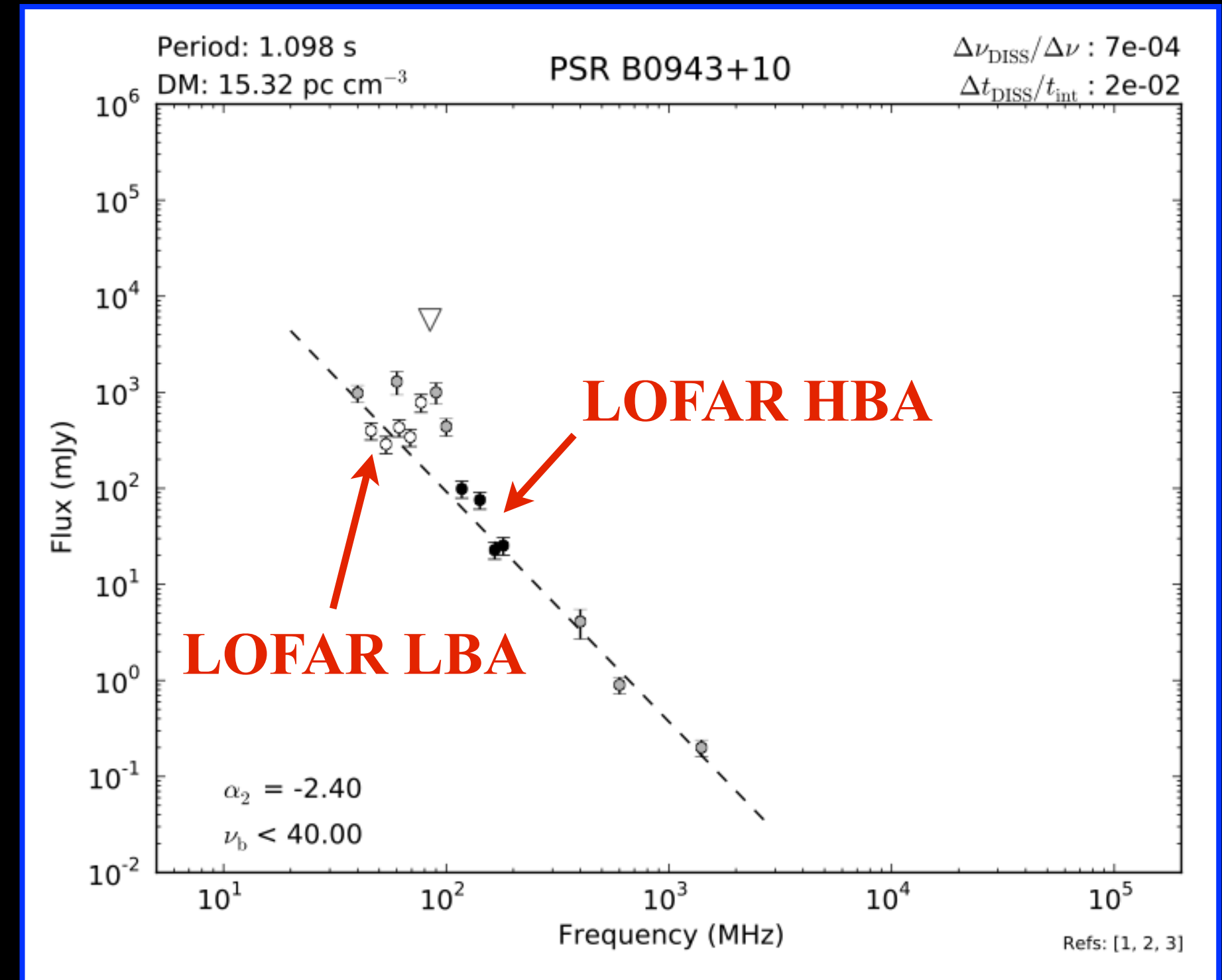
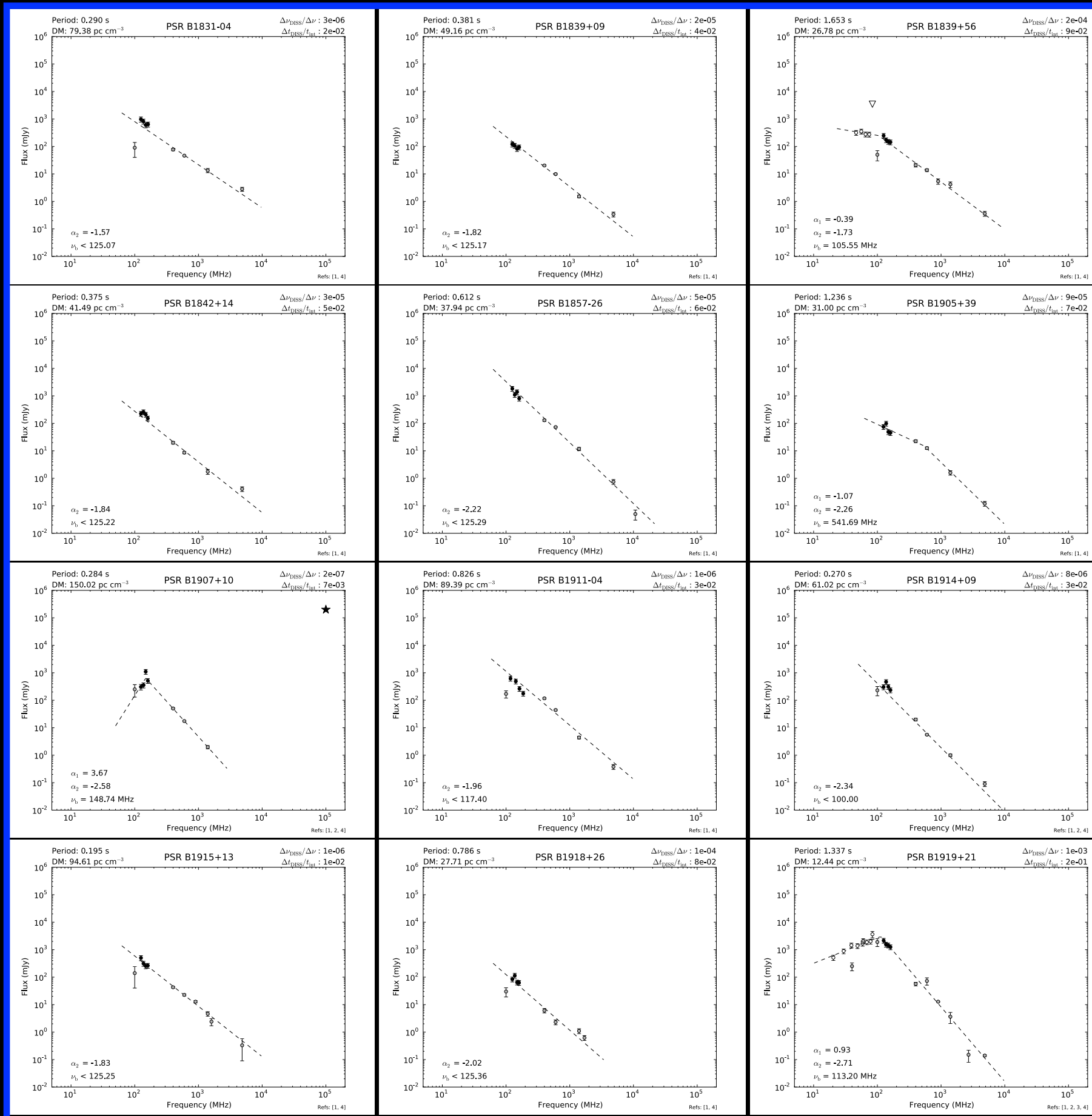
C-RRLs actually seen throughout Galaxy!

Pulsar Surveys with LOFAR



120 pulsars total

PSR B0943+10



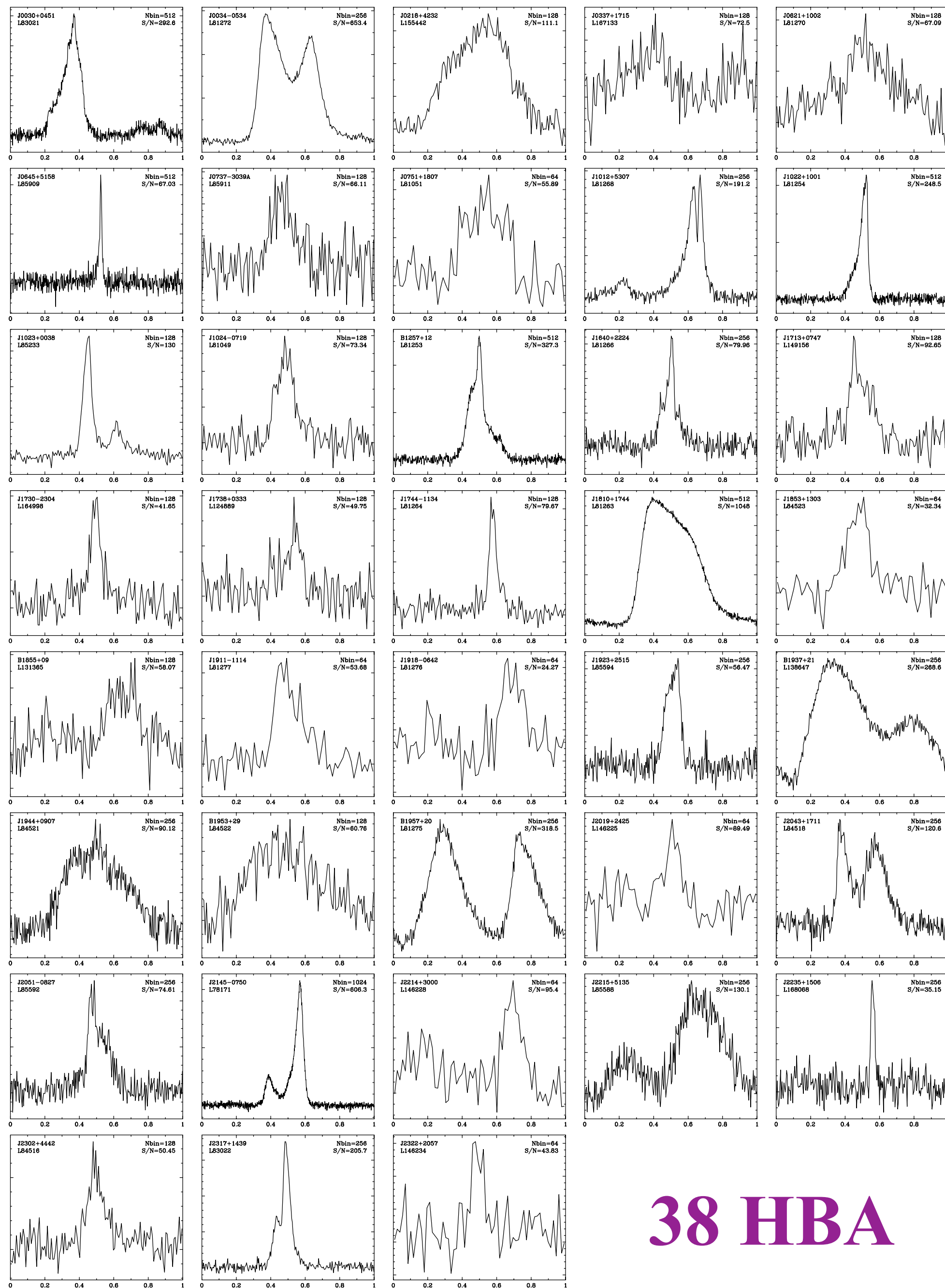
No obvious difference between normal pulsars and MSPs

(Hassall et al. 2014, in prep.)

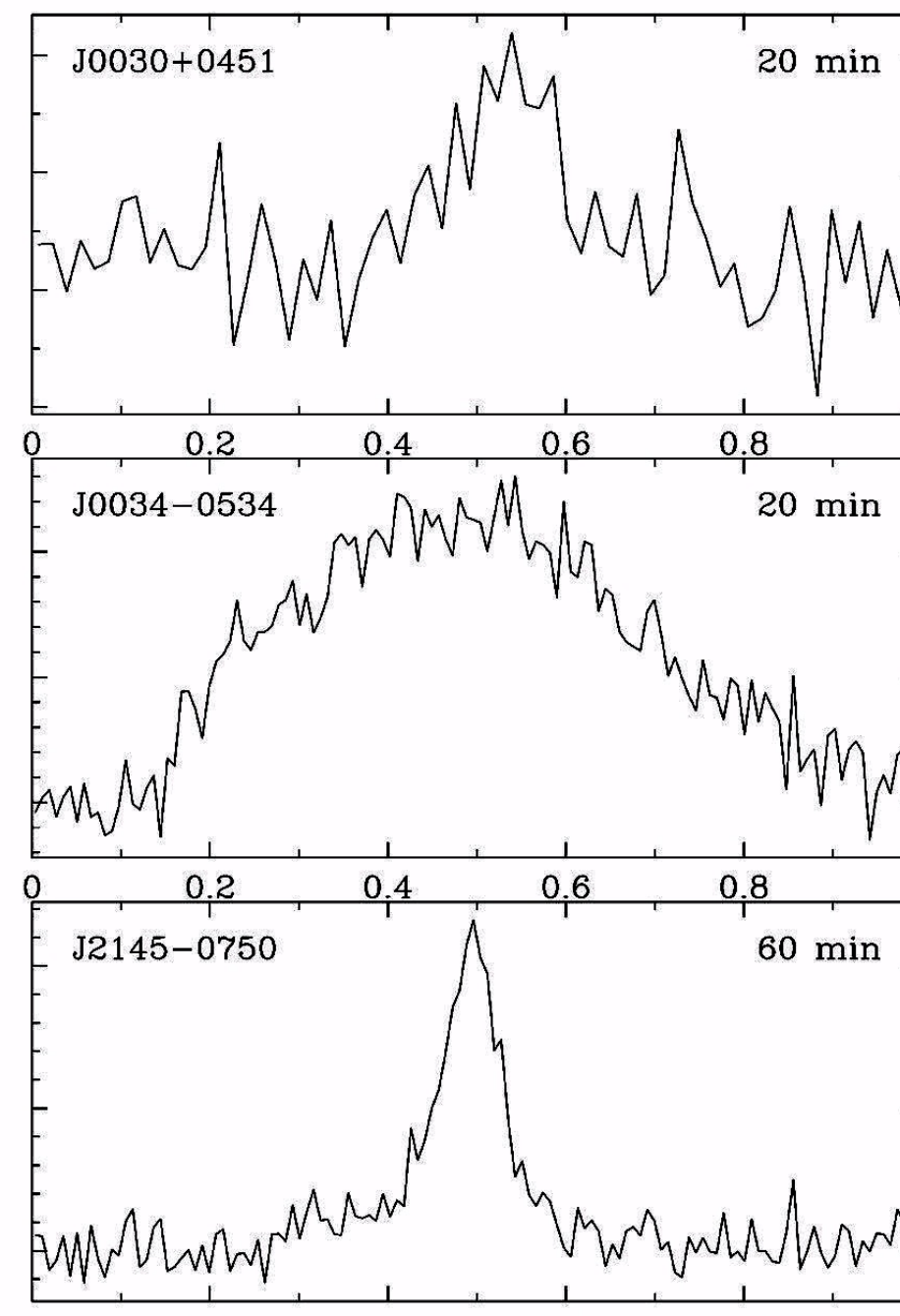
Millisecond Pulsars

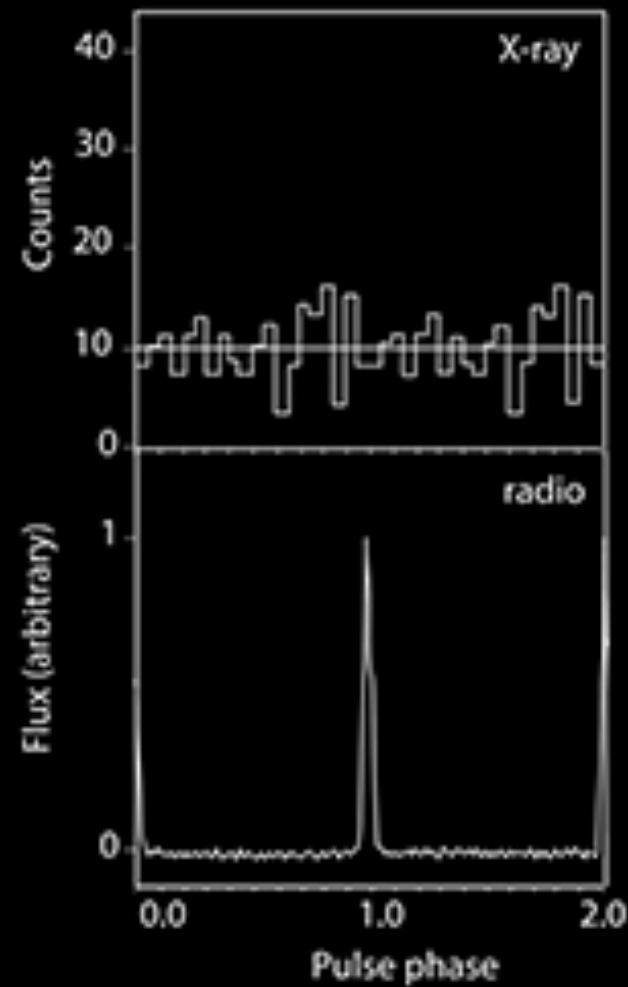
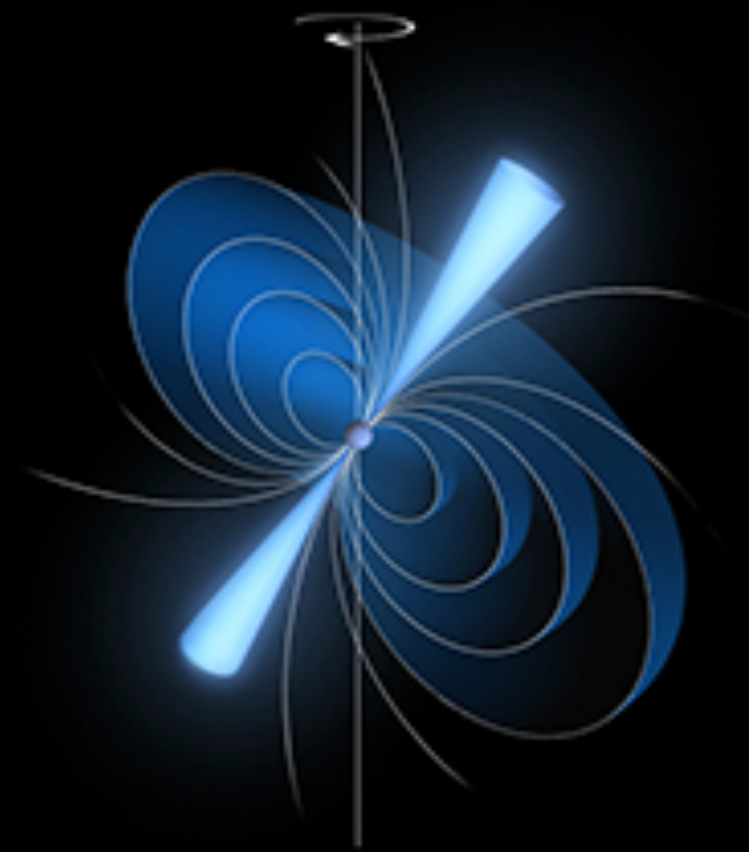
*The premier low-frequency
MSP census*

(Kondratiev, Hessels et al. 2014)



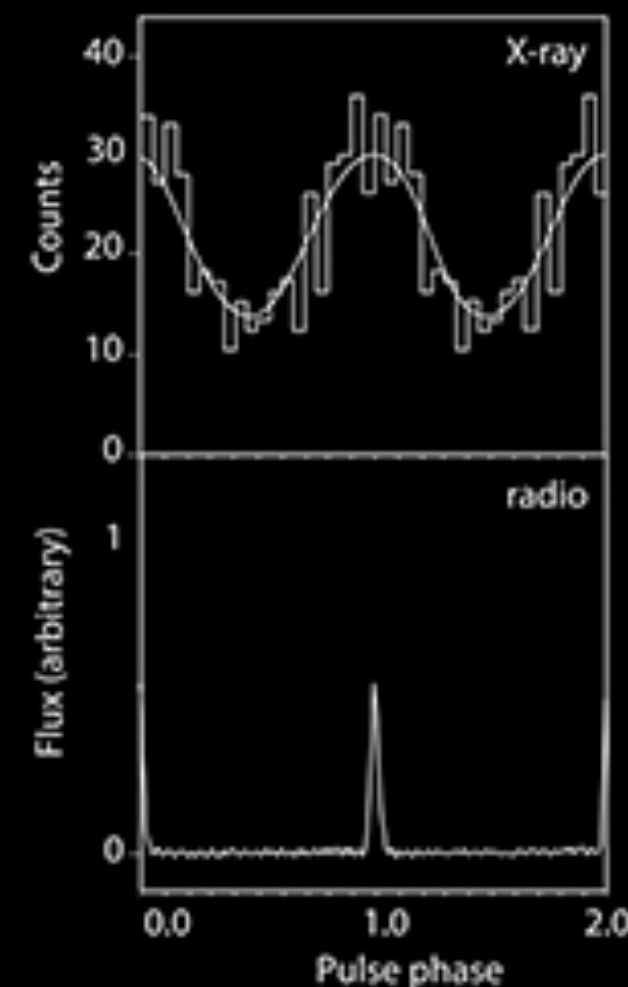
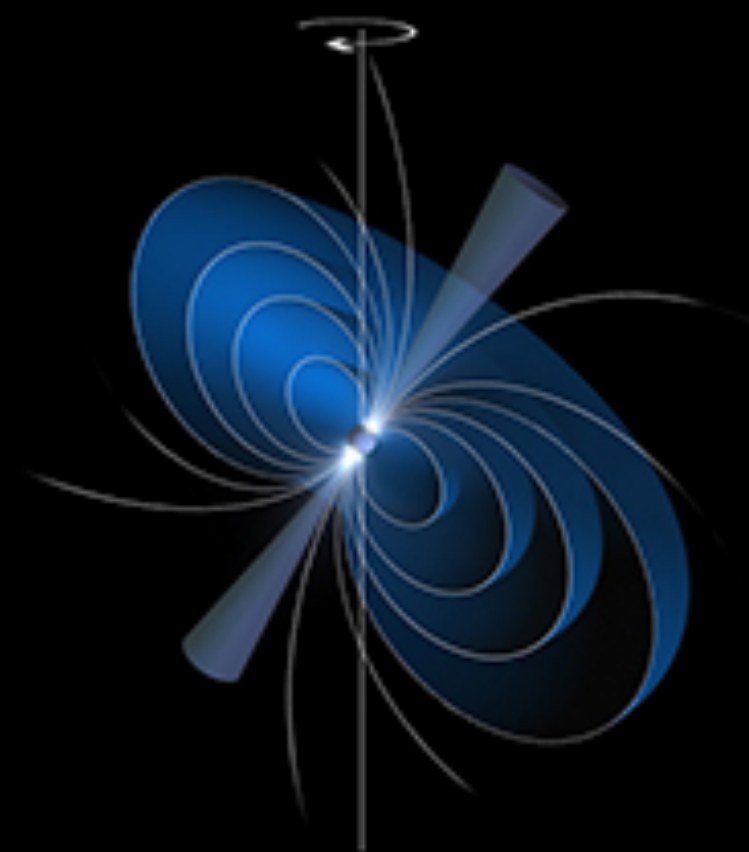
3 LBA





X-ray dim

Radio bright

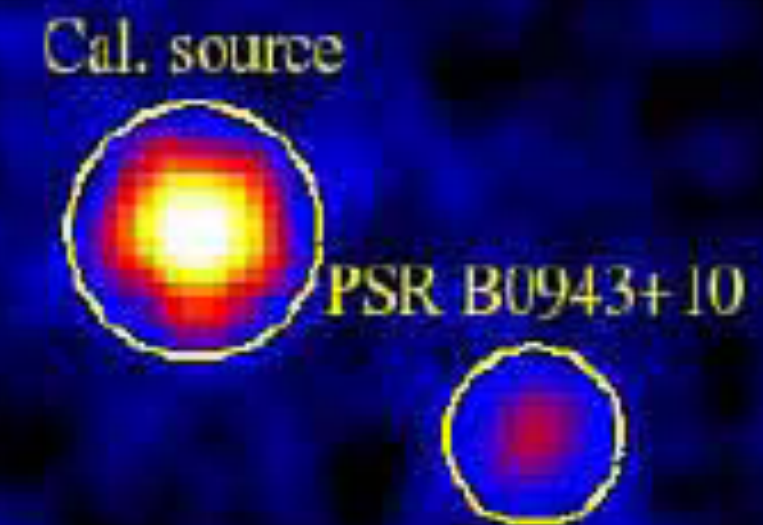


X-ray bright

Radio dim

PSR B1931+24
XMM EPIC 1-2 keV

Simultaneous monitoring of transitions between bright and quiet states

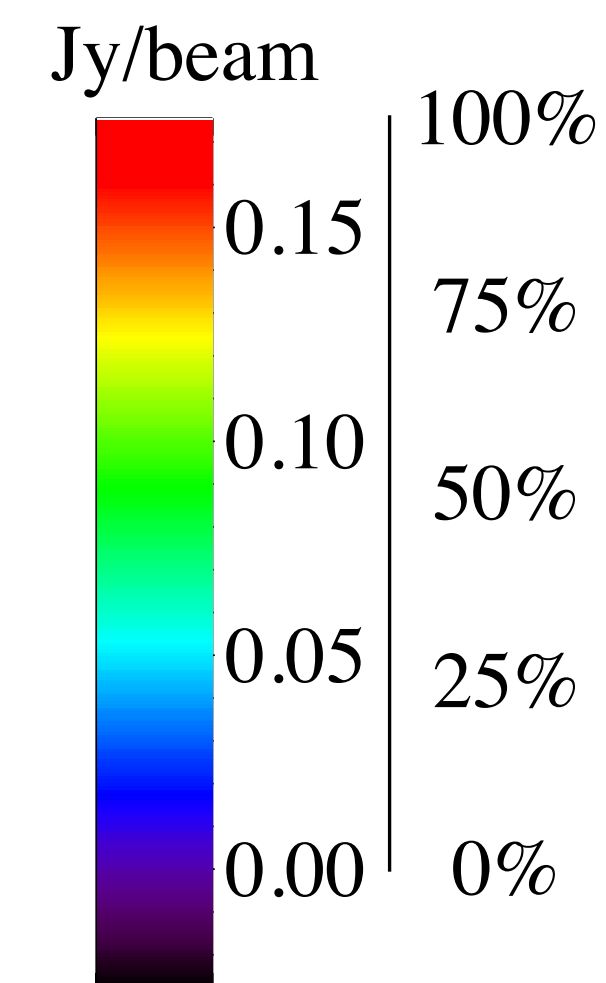
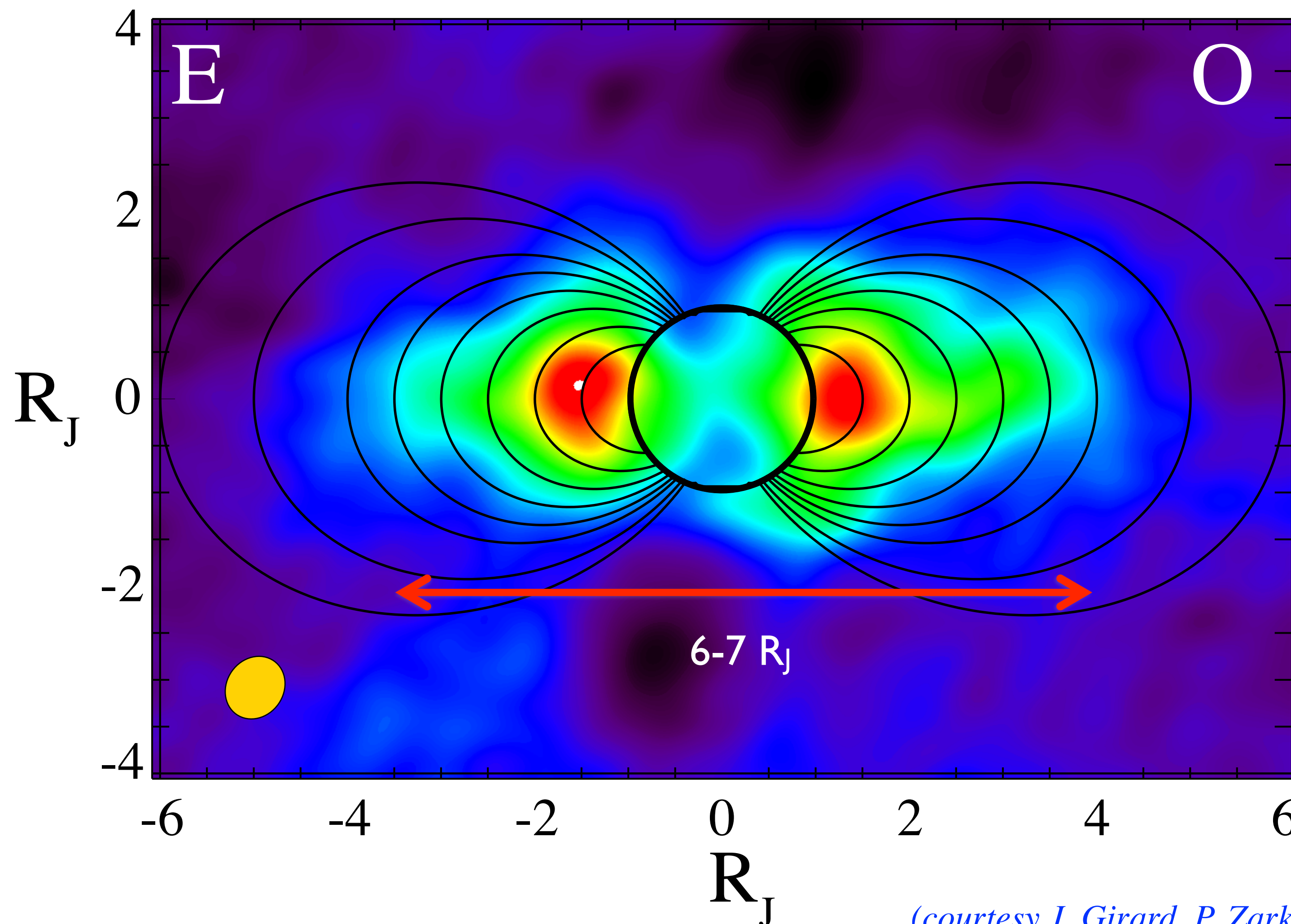


6 x 6 hrs with XMM, LOFAR, GMRT

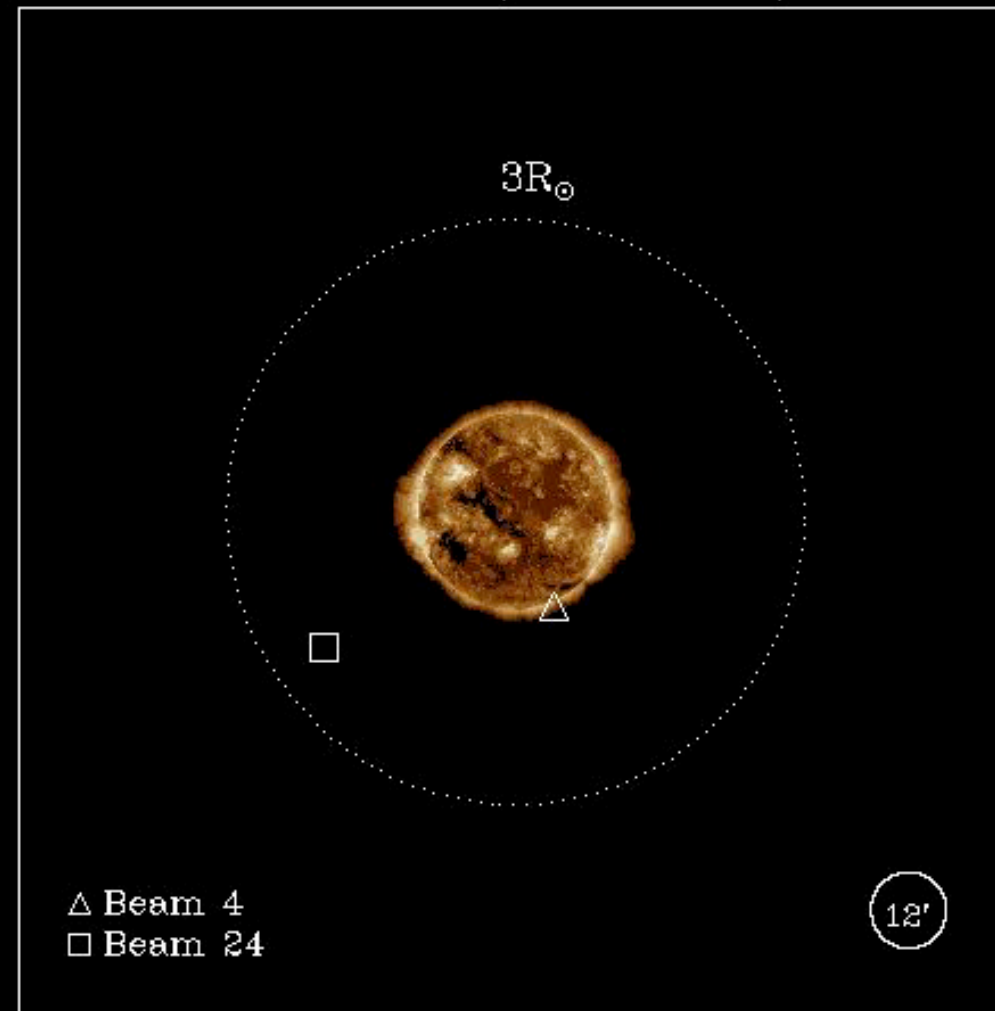
Radio emission from Jovian radiation belts

Rotation & frequency averaged image:

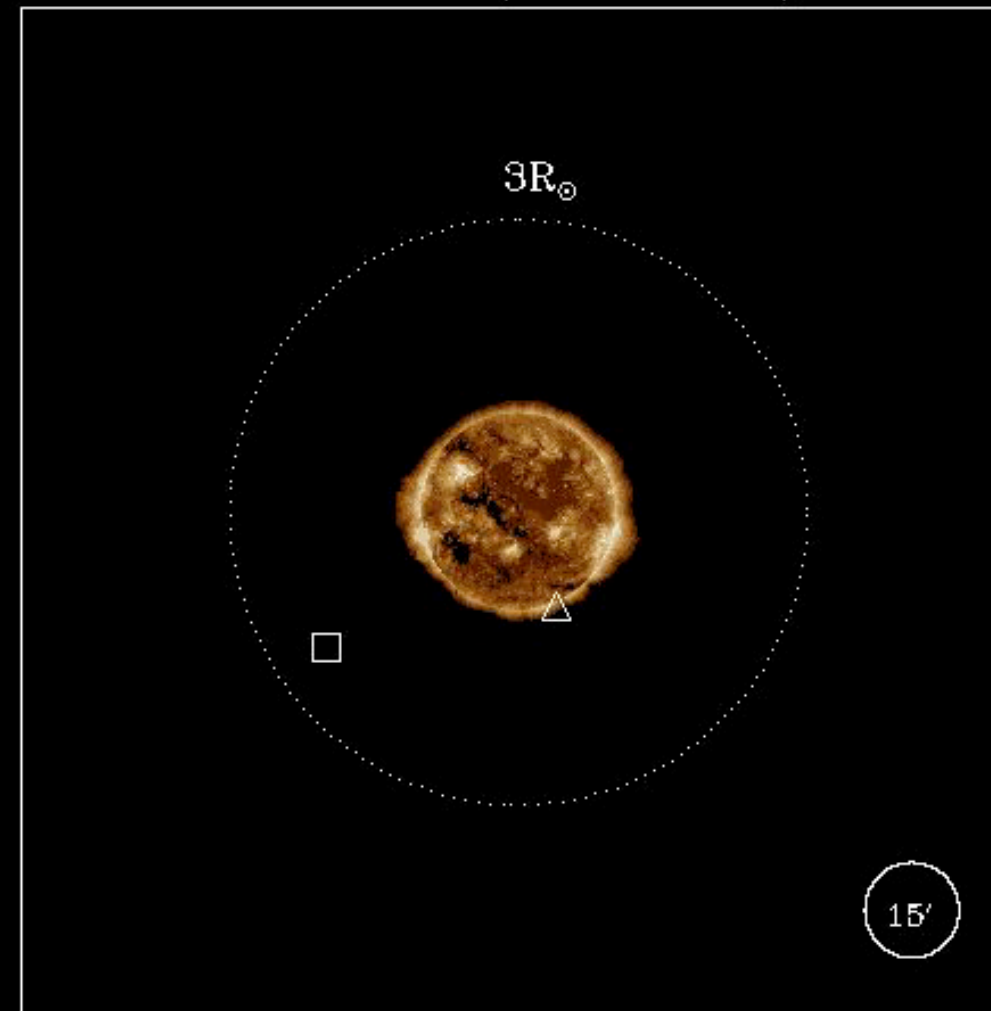
$\Delta f = 127\text{-}172$ MHz,
 $\Delta t = 7$ h
 $uv = 0\text{-}15$ k λ
 Beam = $17.8'' \times 15.5''$
 Pixel = $1''$
 Jupiter disk = $49''$



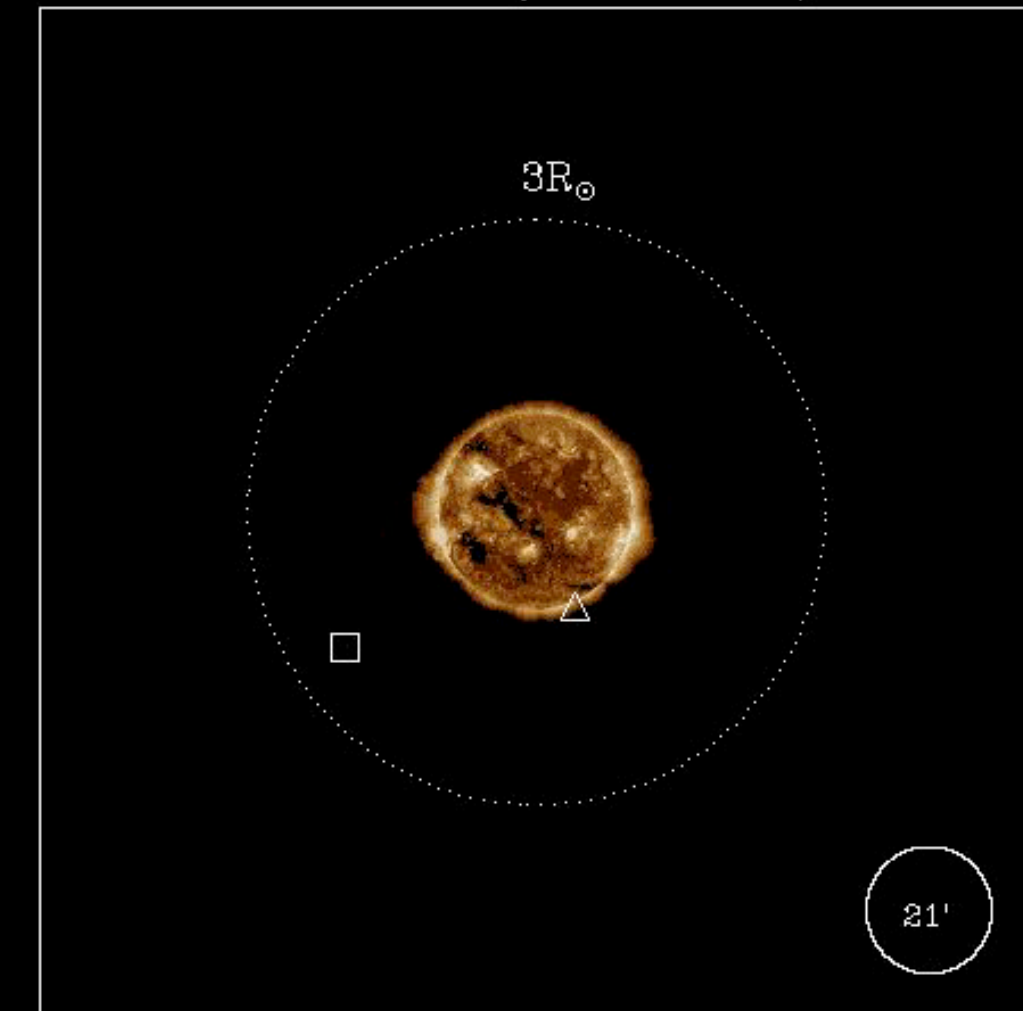
50–55MHz (13:08:00 UT)



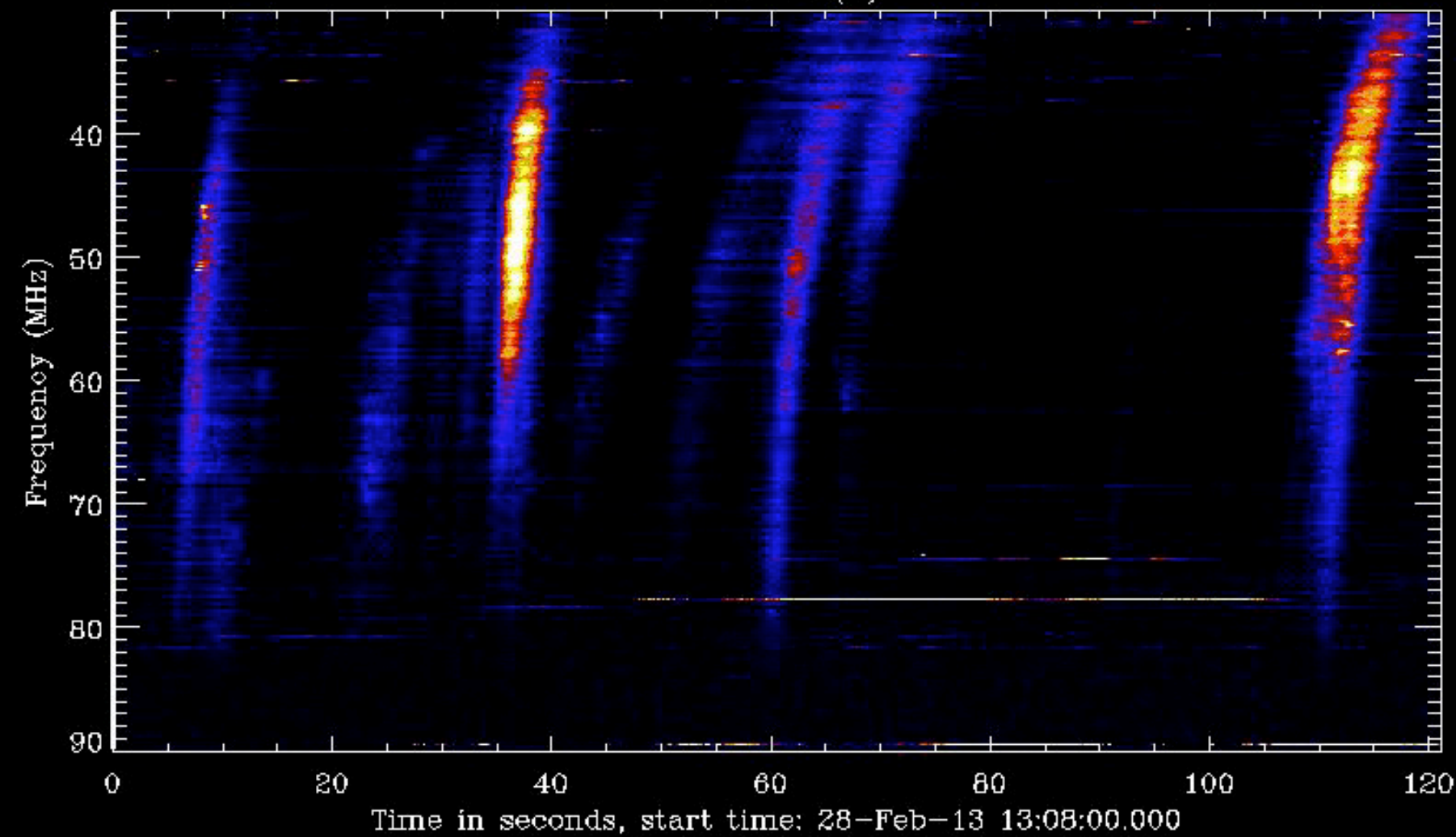
40–45MHz (13:08:00 UT)



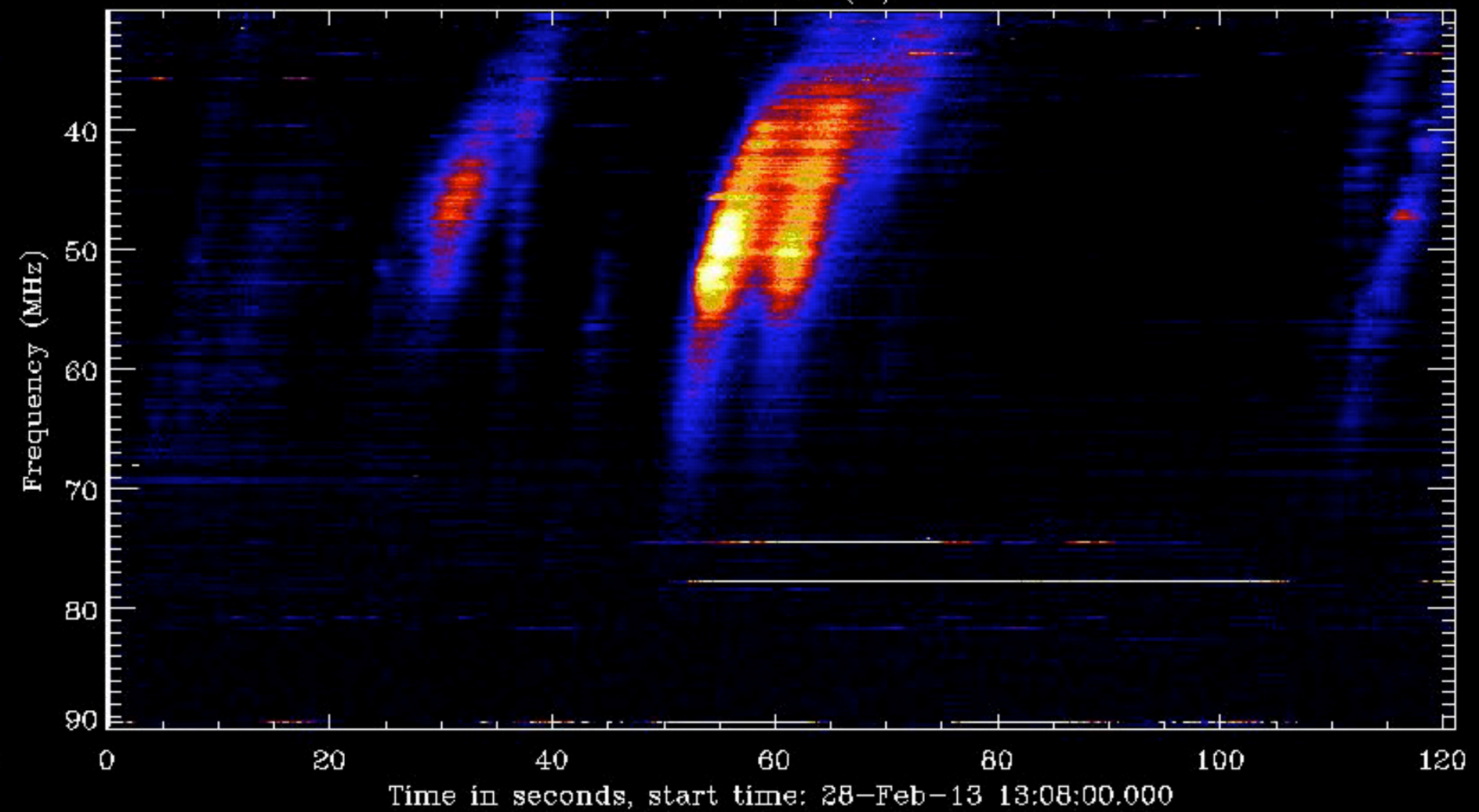
30–35MHz (13:08:00 UT)



Beam 4 (△)



Beam 24 (□)



LOFAR Science 2014

LOFAR Users Meeting

LOFAR Community Science Workshop

First Science with LOFAR's First All-Sky Survey

7-11 April 2014, Amsterdam, The Netherlands

<http://www.astron.nl/lofarscience2014>

Summary

Takeaway Points

- ➔ *LOFAR is up and running and generating great data*
- Hardware status of the LOFAR array is excellent*
- Proposal for Cycle 2 observations due March 7, 2014*
- MSSS HBA survey complete, catalog release mid-2014*
- MSSS Science Workshop planned for April 2014*
- LOFAR is great for a wide range of science*



LOFAR

The End